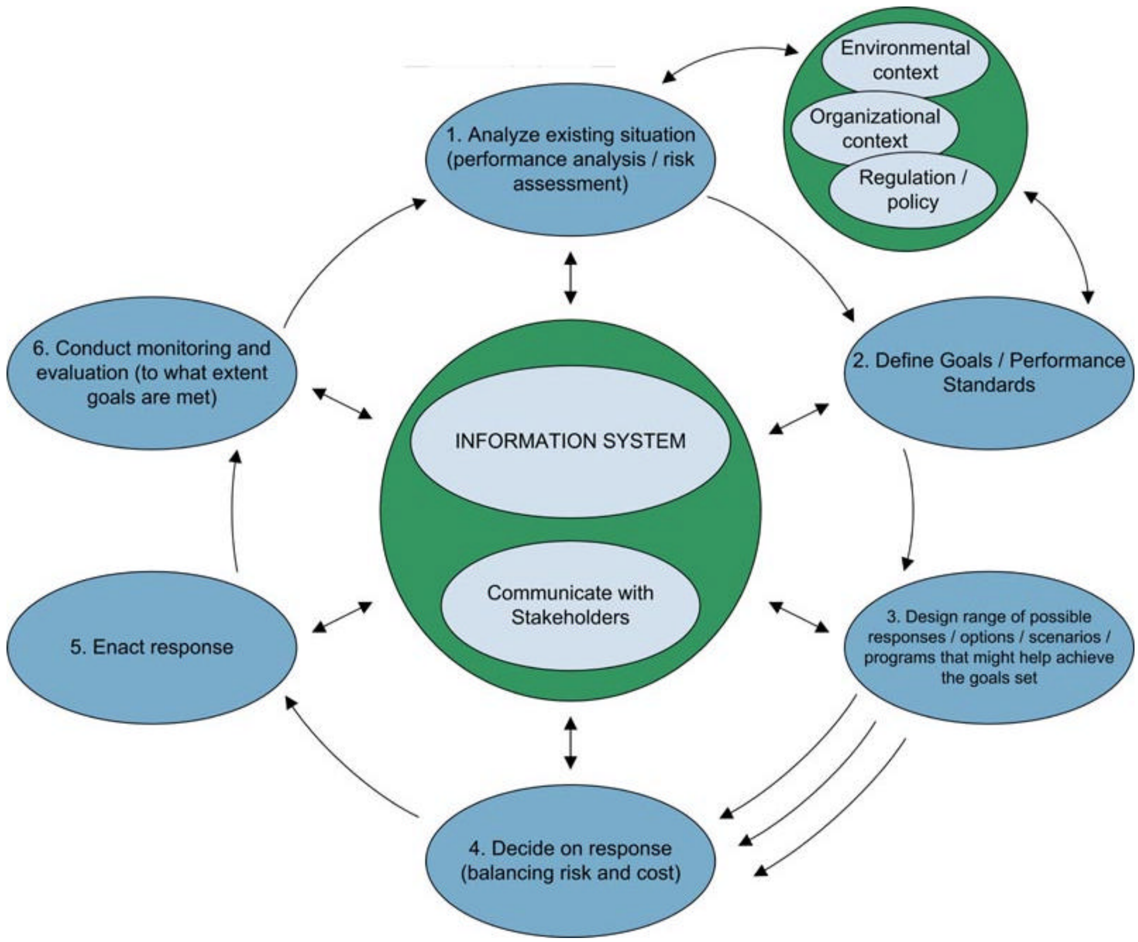
National Decentralized Water Resources Capacity Development Project



Decentralized Wastewater System Reliability Analysis Handbook

Stone Environmental, Inc.
Montpelier, Vermont

June 2005

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Submitted by Stone Environmental, Inc. Montpelier, Vermont

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EXECUTIVE SUMMARY

Project Background

Decentralized systems are a permanent part of the wastewater infrastructure. Understanding how to improve the performance of these systems is crucial to allocating the often-scarce resources available for hardware and management. While using an asset management framework for centralized wastewater system management has become common in some countries, asset management has not been typically used in the decentralized field.

Asset management is based on a simple idea: Find out what your assets are, where they are, what condition they are in, and how they affect your ability to meet performance requirements; then use this information to make decisions about investing in new assets and maintaining existing ones.

Primary barriers to using asset management in the decentralized field have been the lack of information about the reliability of decentralized wastewater systems and components or capacity to evaluate that performance against engineering, ecological, public health, and socioeconomic goals. Removing these barriers will help realize the use of asset management to evaluate the effects of different management approaches and to choose the least-cost way of meeting performance goals.

Developing a framework through which a practitioner may select appropriate asset management and reliability assessment tools and then understanding the tools available to practitioners represent the critical elements of this project. This handbook was developed to allow the results of this work to be easily incorporated into the decision-making of communities, regulators, and the design community. A list of future research needs, data needs, and additional useful tools are also incorporated into the handbook.

The Framework

The framework provides an overarching process to guide handbook users to the tools best suited to help them manage the reliability and cost of their particular decentralized wastewater treatment system(s). The framework guides the users through a step-by-step process, alerting them to different issues they will need to consider and directing them to an appropriate set of tools relevant to their situation for each one. Use of these tools will assist in optimal management of the assets and risks associated with decentralized wastewater treatment.

The framework provides a generic process applicable to most situations, though three points qualify this statement. First, real-life situations do not always occur in simple logical steps, and some aspects of the process may have already occurred when a user picks up the handbook. Despite this, a user will be able to use the framework to identify the missing parts of the process that will help accomplish the best management of the reliability and cost of the system(s) in question. Second, iteration of some steps may be required before further steps can be completed. Third, different tools will be applicable with different US EPA management models, and some tools will be applicable differently, depending on the US EPA management model.

The Tools

With the framework in place, one method of thinking through the inputs and choices is provided at a broader level. To implement the principles of asset management, the decentralized wastewater industry requires a specific set of tools to help a decision maker gain the appropriate information to improve decision-making. This project identified three broad sets of tool types that are useful for asset management.

The focus of this project was on reliability and costing tools, with less effort applied to information systems. To date, a large suite of tools believed to be applicable to the decentralized wastewater industry has been identified. A subset of these tools is presented in detail in this handbook, providing the target audience(s) with information necessary to determine whether the tool is a good choice for their situation.

The reliability tools in this handbook (failure curves, process reliability, failure modes and affects analysis, and geographic information systems) provide specific tools for understanding the useful life of system components, developing preventative maintenance programs, designing treatment trains to assure performance reliability requirements, troubleshooting system problems, determining environmental and human health impacts from system failure, assessing appropriate project designs, and tracking information.

The costing tools in the handbook (life-cycle costing, activity-based costing, and the risk-cost model) provide ways for users to fully understand the true cost of alternatives and assist decision-making processes based on the cost of accomplishing tasks and understanding the consequences of non-performance. These tools allow decision makers to determine how best to allocate resources on the most critical maintenance activities, to ensure that fiscal resources provide reliability, and to protect environmental, human health, social, or property values as determined by the jurisdiction.

Additionally, the handbook incorporates case studies and examples to highlight places where the tools have been used or what benefit their use may have entailed, had they been used.

Intended Audience(s)

The work of this project has application for a wide range of audiences. How the information, tools, and framework are used will vary by audience depending on their needs and specific circumstances. Practitioners, maintenance management entities (which have no formal, long-term responsibility for the wastewater treatment systems), responsible management entities (RMEs, which either own the treatment system or the permit for it), regulators, and policymakers make up the predominant possible users, though some manufacturers may have interest as well. While they are not a primary audience of this work, homeowners should be the ultimate beneficiaries of better decision-making by having the most reliable and cost-effective treatment and dispersal options available to them.

Practitioners, maintenance management entities, and RMEs would likely use specific tools in the handbook to achieve greater cost-effectiveness, fewer maintenance requirements due to greater reliability, or some combination of both. Regulators, policymakers, and some RMEs would likely be interested more in the framework and the tools that consider cost and reliability issues more broadly, though they may also be interested in specific tools to address current issues of concern to their jurisdictions.

Data Needed to Use the Tool(s) and Costs of Using the Tool(s)

Data needs for application of the tools of this project vary widely. In some cases, the data will exist and be simple to acquire, while in others, little or no data will exist and data will need to be developed for successful application of the tool. Similarly, the cost of implementing the use of these tools will vary. In many cases, the cost of using the tools will be limited to the time it takes for a person to learn how to use them. In others, data acquisition, information management systems necessary to manage the data, and assistance to interpret the data will be required.

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1 INTRODUCTION

“Peach Lake Polluted—Failed Septic Systems to Blame;” “Dirty Drinking Water at Joe’s Mobile Home Park—Residents Report Gurgling Sounds From Toilets;” “New Septic Technology Fails—$20,000 Later Ocean Still Being Polluted.”

These and similar headlines are all too familiar. The need for greater assurance that decentralized systems will work as advertised, will last for a long time, and will remain affordable is rising in importance around the country.

Today there is not enough funding available to care for the existing centralized wastewater infrastructure, both for reconstruction of old systems and for managing the programs necessary to oversee these systems. Funding shortages over the next 20 years for capital and operation and maintenance costs are estimated at $122 billion and $148 billion dollars, respectively (US EPA 2002a). Additionally, funding shortfalls for adequate management of Clean Water programs are reported to be in the hundreds of millions of dollars per year. The centralized wastewater treatment industry is seeking solutions to these challenges. Better decision-making tools and analyses of managing and repairing centralized systems are evolving in the industry and are being slowly implemented across the country in the form of asset management as a partial solution to address funding gaps.

The funding gaps described above highlight a myth that has existed in the US for decades: the notion that decentralized wastewater solutions are temporary solutions, in place until communities install centralized systems. The US Department of Commerce reports that 25% of all American households, and 40% of new developments, rely on decentralized wastewater systems (US Department of Commerce 1997).

The myth that decentralized wastewater systems are temporary solutions is partly responsible for the way decisions regarding decentralized wastewater systems were made over the decades. A common editorial accompanying the headlines that opened this introduction might be “Town Should Consider Laying Sewers” as the answer to the problems. Other reasons include property rights issues, perceived low health and environmental risks, and socio-economic impacts.

As the funding gap for centralized systems increases, policymakers at the federal, state, and local levels are realizing that decentralized infrastructure is likely to be their primary choice in many areas for the foreseeable future, both to remediate existing health and environmental problems and to foster economic development initiatives (for example, US EPA 1997). As the range of potential solutions changes, there is interest in ensuring that decentralized infrastructure is installed and maintained in economically sound ways and that these systems last as long as possible. Now is the time to professionalize decision-making, maintenance, technology, and ownership issues in the decentralized wastewater industry.

Many people may argue that good data for use in applying these tools to the decentralized industry do not exist, particularly in the case of reliability tools. The centralized wastewater industry is dealing with this challenge, as other industries have in the past. While a repository of information is a critical need and a critical element of the success of following the framework provided in this handbook, lack of data must not prevent the industry from beginning down the path. (See Chapter 8, *Data Needs*, for a more detailed discussion of data availability and data management.)

More data for application of reliability and costing tools exist than most people realize. The challenge is to find data within existing decentralized management systems and to help those who possess it realize what they have collected. The examples provided throughout this handbook demonstrate that enough data exist to enable progress. Methods are available to approximate initial values where data do not exist. While imperfect, the process of improvement begins with initial assessments and gets better with each additional data collection effort. Lack of data is no excuse for lack of progress.

Transforming from a temporary industry to one that will provide much of the nation's new infrastructure over the coming decades is daunting, exciting, and challenging. With this change in attitude will come innovation, many mistakes, and great opportunities. By focusing on how decisions are made, how costs are analyzed, and how the engineering reliability of systems in the field are improved, the industry can minimize mistakes, select wisely from new technology choices, and meet the new infrastructure demands of the nation while improving water quality, public health, and the necessary economic development of communities.

1.1 Decentralized Wastewater Basics

Users of this handbook likely have a significant base of knowledge about decentralized wastewater issues. However, a general background on wastewater systems, the challenges currently faced by the decentralized wastewater industry, and the possible tools and techniques for addressing these issues are provided to ensure a common understanding.

1.1.1 Decentralized System Failure Versus Performance

What constitutes failure of a decentralized wastewater system? Historically, the industry's main definition was effluent surfacing or breakout. The goal was to have wastewater effluent percolate into, and stay beneath, the soil surface. Today, the definition is becoming more inclusive. From the perspective of asset management, any definition of failure can be used, as long as it is clearly stated as a performance standard to be met.

Asset management focuses on performance, which, like failure, has many possible definitions. Performance standards are adaptable to individual jurisdictions in positive ways that are within the abilities of the jurisdiction to accomplish. The idea of system performance blends well with the goal- and performance standard-setting step that is central to the framework presented in this handbook.

Failure is important to define and is a necessary part of the dialogue of asset management. The handbook's focus on performance provides tools and methods to ensure that failure does not occur. Under this approach, when failure does occur, it is anticipated, it has few or no important associated risks, and allowing the failure represents the appropriate fiscal method from which to approach the failure.

Failure and performance are discussed further in Section 3.3.1.

1.1.2 Decentralized Industry Challenges

For the decentralized wastewater industry to be capable and trusted to resolve important, long-term environmental and public health challenges, many obstacles must be addressed. Some can be met using the asset management approaches considered in this handbook. Among these are:

- **Improved alternatives analysis:** Characterizing decentralized alternatives with centralized options in balanced ways is vital to ensuring that good choices are made. Increased knowledge of *failure curves* (Section 5.3) makes more accurate *life-cycle costing* of decentralized systems possible (Section 7.1), so they can be fairly compared with the life-cycle costs of centralized systems.
- **Enhanced maintenance procedures:** In many instances, decentralized systems are not well maintained. Increasing the useful lives of these systems and successfully competing with centralized options requires a focus on maintenance and reliability. *Life-cycle costing* (Section 7.1) can quantify long-term cost benefits that come from regular maintenance or other improvements in reliability, and thereby increase the incentives for maintenance or other changes.
- **Adoption of performance standards:** Historically, decentralized system "performance" meant that effluent did not surface. Research and experience show that, in many cases, soil-based treatment or treatment using other media is required to adequately protect human and environmental health. These issues will become more important as newer technologies, growth pressures, and demands to use marginal land for development emerge. Understanding the probabilistic nature of *process reliability* (Section 5.6) can help with setting meaningful standards for effluent treatment and with cost-effectively determining whether the standards are met.
- **Enhanced technology development:** Technology is developing rapidly in the decentralized wastewater industry. This trend helps the industry meet performance goals, provides real solutions for denser developments, and allows for the increased maintenance and management that newer technologies tend to require. Tracking *failure curves* (Section 5.3) and finding the most common *failure modes* (Section 5.5) can provide feedback to regulators and manufacturers that spurs continued technology improvements.
- **Public education and acceptance:** Without public understanding, centralized systems are likely to be the preferred wastewater solutions. Demonstrating the success and relevance of decentralized technologies will enable the public to view the industry as a viable alternative. Setting clear *performance standards* (Section 5.1) and documenting how well they are met

gives a comprehensible basis for demonstrating what decentralized technologies are capable of doing. Public education and acceptance can also be promoted by improved alternatives analysis (above).

1.1.3 Tools and Techniques

Addressing the challenges facing the decentralized wastewater industry requires a framework and many specific alternative methodologies and tools. The purpose of this handbook is not to illustrate each necessary tool, but rather to provide solid, tested tools and methods to improve performance, enhance reliability, ensure sound fiscal choices, and develop solid methodologies. The handbook provides a single framework and seven tools, each described in some detail. This suite of tools and methods will enable practitioners to make progress on each of the challenges identified above.

A framework is a way to think through issues, either from the natural beginning to the end, or by beginning where the process currently resides and moving forward. The framework provides the decentralized industry with a simple method for developing solutions, from the conceptual identification of problems and issues through implementation. This framework can assist communities in developing a suite of real alternatives that meet their goals and regulatory obligations. Regulators can use the framework as a way to consider performance standards, set regulatory criteria, or to ensure that compliance is in tune with proposed solutions and that the preferred alternative has been fairly and reasonably determined.

The reliability tools in this handbook (failure curves, process reliability, failure modes and affects analysis, and geographic information systems) provide specific tools for understanding the useful life of system components, developing preventive maintenance programs, designing treatment trains to ensure performance reliability requirements, troubleshooting system problems, determining environmental and human health impacts from system failure, providing a basis for demonstrating the capability of decentralized technologies, assessing appropriate project designs, and tracking information.

The costing tools in the handbook (life-cycle costing, activity-based costing, and the risk-cost model) provide ways for users to fully understand the true cost of the alternatives and assist decision-making processes based on the cost of accomplishing tasks and understanding the consequences of non-performance. These tools enable decision makers to determine how best to allocate resources on the most critical maintenance activities, to ensure that fiscal resources provide reliability and protect environmental, human health, social, or property values as determined by the jurisdiction.

1.1.4 Data and Information Systems

The tools in this handbook have one common denominator—information. All of the tools and methods require information to produce useful results. Practitioners should consider their willingness to compile and maintain the necessary data systems as they contemplate using these tools. Most do not require high technology data systems. The level of investment in technology needs to reflect the context (for example, the US EPA management model and the level of resources available to manage the assets). The key is that those responsible for management are thinking about the principles outlined in this handbook—understanding patterns in reliability and failure, being clear and consistent about costing processes, balancing risk and cost explicitly, and so on. Basic spreadsheets or databases that focus on key performance information might be adequate for small-scale or simple operations and jurisdictions. More intricate spreadsheets, databases, or proprietary information systems probably make sense for those operating at Level 4 or 5 or for larger regulatory jurisdictions.

Localized application of these tools may be initiated by relying on information from other jurisdictions, manufacturers' information, professional judgment, and methods designed to estimate surrogate data. These methods should be used along with a commitment to begin collecting local data as implementation is initiated. A commitment to continuous improvement is central to all elements of asset management, and it will be critical to update initial assumptions with better, perhaps locally-derived information, and to allow for the optimization of the system.

1.2 Audiences for This Handbook

This handbook was written to be useful for the decentralized wastewater practitioner, a term which encompasses designers, installers, operators, and maintainers. It was also written to have useful information for a manager of a responsible management entity (RME), who may be thought of as a practitioner operating with more control over when and how to maintain the systems.[1] Finally, its information is useful to a regulator[2] who wishes to ensure that decentralized wastewater treatment systems protect human health and the environment without putting an undue financial strain on the owners.

Reliability and costing tools are important to different people because each tool can help answer different sets of questions. The tools described in the handbook are relevant to different stakeholders' fields of interest and responsibility. The reasons why the tools can help each party answer reliability investment questions are also described in the following sections. The tools likely to be most useful are identified in Table 1-1.

1.2.1 Practitioners' (Designers, Installers, Operators, or Maintenance Management Entities) Questions and Perspective

Wastewater practitioners are concerned with their own cost perspective and that of their customers, the homeowners. Practitioners may be interested in avoiding certain types of failure, such as surfacing effluent, effluent backup, odor, or not meeting effluent treatment standards. Practitioners may also be concerned about public health or ecological damage.

Practitioners are faced with many decisions about the most cost-effective ways to ensure reliability of the onsite systems that they design, operate, or maintain. In some instances, these

[1] For more on what an RME is, see section 3.3.3.
[2] Unless otherwise noted, references to regulators and regulations in this document are to environmental and health regulators and regulations.

decisions are imposed on practitioners either by regulation or by other constraints. Some of the common decisions practitioners may contemplate include how to maintain a profitable business while still improving the reliability of the systems they operate.

Table 1-1
Reliability and Costing Tools Matched With Most Likely Tool Users

Tool	**Useful to**		
	Practitioner[1]	**Responsible Management Entity (RME)**	**Regulator**
Reliability Tools			
Actuarial studies producing failure curves	X	X	X
Cohort analysis	X	X	X
Process reliability	X	X	X
Failure modes and effects analysis		X	X
GIS-based tools		X	X
Probability assessments[2]	X	X	X
Critical component analysis	X	X	X
Statistical field sampling of system performance			X
Systematic troubleshooting	X	X	X
Costing Tools			
Life-cycle costing (LCC) / Cost-effectiveness analysis (CEA)	X	X	X
Activity-based costing (ABC)	X	X	
Risk-cost modeling	X	X	X
Analysis of asset cost inventories and databases	X	X	
Economic life replacement analysis	X	X	
Cost benefit analysis (CBA)		X	X
Integrated resource planning (IRP) framework		X	X
Cost perspective tests		X	X

[1] Practitioner here refers to designers, installers, operators, and maintainers
[2] Italicized tools are described briefly in Appendix A.

Decisions for designers or installers include making the best choice of parts or materials (for example, pumps, pipes, or stone for leachfields), buying or specifying better quality to ensure longevity and reliability, or designing systems to enable easy maintenance later (for example, including distribution boxes, inspection ports, or risers) even though these components have an initial cost. Designers might also want to know the long-term operation and maintenance costs of different technological options and how much redundancy is cost-effective to build into the system to reduce potential failure impacts.

Decisions made by operators or maintainers include:

- How often to inspect systems
- How proactive or reactive maintenance regimes should be
- What aspects of systems must be monitored
- Whether it is worth taking measurements to keep an ongoing record of system condition
- Whether it is worth entering results into a database
- Whether pumpouts should occur according to a prescribed schedule or as needed
- What level of guarantee should be given

The reliability tools likely to be useful to practitioners include failure curves, cohort analysis, process reliability, probability assessments, critical component analysis, and systematic troubleshooting. Of these, failure curves, cohort analysis, and process reliability are discussed in detail in this handbook.

Choice of Materials and Equipment

Sometimes the cheapest possible materials and components are chosen when installing or repairing systems. Two examples are:

- Low-quality pipe. Drainage pipe is softer than sewer pipe, and therefore does not last as long.
- Leachfield stone. Unwashed gravel is inexpensive, but the fine material washes off and clogs the stone/soil interface.

Both of these examples can substantially reduce the life of the system, leading to higher costs in the long term. The question remains of how to create incentives to ensure that higher quality components are used.

Practitioners have expertise in the functioning of onsite systems, and these tools can increase their expertise. A dilemma for the practitioner is that persuasion is the primary tool available to get system owners to agree to and pay for activities that cost money up front but prolong the life and increase the reliability of the decentralized system. For that reason, many of the practitioner's uses of most of these reliability tools may be more effective if the regulator is on board and helping to set requirements for system owners.

The practitioner can use **failure curves** to estimate how long a system component will last, so that inspections or pro-active replacement of a component like a pump can be accomplished in a timely manner. The practitioner can also use failure curves to develop and test hypotheses about failures—if a part is repeatedly failing faster than is expected, perhaps the practitioner has been installing it incorrectly or is using it in an environment in which it was not designed to be used. Finally, a practitioner could use failure curves to see whether greater attention to a system is warranted in any particular phase of its life, for example, the first months after start-up or after 20 years.

Cohort analysis is used to draw conclusions about the performance of groups of systems. Defining cohorts—which systems are similar enough to be lumped together—is a step along the way to applying failure curves at the system level.

Process reliability is most useful in design of wastewater treatment systems. A desired level of process reliability may be dictated by a regulator, or the practitioner may decide to interpret an absolute value as one to be achieved 99.9% (or 90%) of the time and use the corresponding design value.

The Value of Considering Ongoing Operating and Maintenance Costs

For individual system designs, a designer may have an option of designing a filled (mound) system that might cost $15,000, or a pre-treatment unit and subsurface system for a similar construction cost. Since the construction costs are similar, the decision about which system to choose rests upon the O&M costs and future replacement costs for these two options.

Where failure curves show a wear-out period at the end of a system or component's life, **probability assessments** can be used to condense the information from failure curves into a single number, like mean time before failure. **Critical component analysis** can be used to identify those components that most often trigger failures (such as pumps, alarms, valves, septic tanks, grease traps, or distribution boxes). **Systematic troubleshooting** standardizes the procedures used to diagnose and repair systems that are not meeting performance standards, which can make it easier for multiple employees to make consistent diagnoses and report similar problems.

The range of costing tools likely to be useful to practitioners includes life-cycle costing, activity-based costing, risk-cost modeling, analysis of asset cost inventories and databases, and economic life replacement analysis. This handbook focuses on the first three tools.

The **life-cycle cost** tool is the most useful tool for designers or manufacturers of onsite systems. The design stage holds the greatest opportunity to influence the long-term cost of a system and to optimize its life-cycle cost. The tool may be used to evaluate systems with different designs and subcomponents in order to minimize both operation and acquisition costs.

For practitioners, knowing the **life-cycle cost** of different systems they install or maintain means that they can provide homeowners or communities with solid information about system choices and appropriate maintenance regimes. **Activity-based costing** might allow practitioners to assign true costs to activities like inspections, repairs, and responses to different types of failures. Asset cost inventories or databases containing reliability data could be created and maintained by practitioners (including pumpers, installers, operators, or maintainers), and could include any quantitative or qualitative information gathered during contact with a system. If this information is computerized, it is available for analysis by practitioners and other parties. **Analysis of asset**

cost inventory is used to look for trends so that practitioners can be proactive about maintenance and make informed decisions; it might be conducted as part of an annual engineering review.

1.2.2 Questions and Perspective of a Responsible Management Entity (RME)

The RME perspective is relevant to communities managing their own wastewater treatment systems or other entities managing a set of systems. Reliability and costing tools and principles relate to RME management model 4 of the US EPA voluntary management guidelines (where the RME maintains the systems, but the homeowner owns them) or model 5 (where the RME owns the collection and treatment assets and is responsible for meeting all permit requirements). There are relatively few RMEs in existence at this point, and understanding their interests and abilities will evolve as RMEs become more common.

As owners or operators of onsite systems, RMEs have an interest in medium- and long-term investments in system reliability. RME concerns include surfacing effluent, effluent backup, odor, and exceeding nutrient or other water quality limits and associated ecological impacts. RMEs, particularly larger model 5 RMEs that have economies of scale and a corporate structure that internalizes both capital expenditure and operations and maintenance (O&M) costs, potentially have use for all of the reliability tools discussed in this handbook. Statistical field sampling, however, because of its high cost, may be beyond the scope of existing RMEs.

The RME can use the tools used by practitioners for all of the reasons a practitioner would (see previous section). Since the RME has more authority than the practitioner to increase or decrease O&M (and to profit) in response to the information generated by these tools, the motivation is greater to use them.

An RME is more likely to have responsibility for a geographically clustered set of systems. **GIS-based tools** can be used by an RME to provide or refine spatial information used in cohort analysis and failure curves (for example, depth to groundwater, or distance to surface water) or to model the impact of onsite systems on water bodies (see Section 5.4). In order to ensure long-term system reliability, RMEs may want to know the dominant modes and causes of failure of these systems, the likely consequences (financial and otherwise) that accompany failures, and the most inexpensive ways of repairing, delaying, or avoiding failures. If the RME has installed a large number of virtually identical systems, the effort that goes into **failure modes and effects analysis** can be repaid by deep insights into how to most cost-effectively coax satisfactory performance out of those systems.

RMEs will also be interested in many of the questions that interest practitioners regarding cost-effective maintenance regimes with the right balance of proactive and reactive maintenance. Questions may include what level of investment is worthwhile to capture data about system conditions and how much homeowner education is cost-effective in improving reliability.

The category of RMEs is broad and contains widely differing capacities for addressing reliability issues. One tool set is suggested here for RMEs. Those with limited capacity may use the tools in a broad-brush approach (or use the thinking principles behind the tool), while better-equipped RMEs may take a more data-intensive, detailed approach. In an environment where managers are increasingly held responsible for the long-term costs of their decisions, RMEs are likely to use any one of the tools listed above.

RMEs can use **life-cycle costing** to optimize design, choose between design alternatives, or optimize maintenance strategies for existing systems. Examining different maintenance strategies might include making decisions between remote monitoring telemetry versus more frequent site visits, or between automatic alarms and meters versus site visits and manual readings. For **activity-based costing** or **life-cycle costing,** an appropriate cost database must be developed that relates costs to activities. The database must be designed so that single assets and their associated costs can be accessed, preferably as a single database that also includes system location, condition, and criticality (a measure of redundancy). The cost elements included depend on the analysis to be performed. **Activity-based costing** could be used to determine the true cost of activities such as inspection or preventive maintenance for a set of systems. Such information informs decision-making so that the most cost-effective solution can be chosen. **Risk-cost modeling** is useful for articulating the true cost of a failure. See the text box below for an example.

Analysis of asset cost inventory involves looking for trends so that RMEs can be proactive about maintenance and make informed decisions. This kind of analysis might be done as a part of yearly engineering reviews and might involve costing dominant failure mode(s) and determining whether it is less expensive to deal systematically with the mode of failure than to allow it to happen and deal with the consequences. For example, RMEs could compare the cost of pumps that failed prematurely with the cost of higher quality pumps with longer lives. They could also compare having pumps or parts to have on hand for an emergency to buying materials on an "as-needed" basis. Economic life replacement analysis would give RMEs a basis for deciding what systems or aspects of a system were worth upgrading, repairing, or replacing, and when to repair or replace. This analysis can be used to maximize equipment and rolling stock life cycles and to understand the cost benefit of different inspection, management, or information systems and permit systems. Cost-benefit analysis can be used to maximize fiscal choices between different systems or maintenance regimes. A large RME might use integrated resource planning and cost perspective tests to develop solutions that are cost-effective on a whole-of-society basis, rather than only considering the cost perspective of the RME or its customers.

> For example, take a pump station installed in an area of high seasonal groundwater tables. This pump station is made of old concrete and has developed some cracks that were repaired twice, but may need to be patched every year until the tank is replaced. If this pump station leaks in groundwater, the water will cause the pumps to work overtime and eventually fail, and the leachfield will be overloaded with groundwater/effluent and will fail by surfacing. To apply the risk-cost tool to this example, one would need to estimate both the probability of the leakage occurring and the costs of the consequences. These costs would include those associated with the failure of the pump itself (replacement cost of the pump) and failure of the leachfield (potentially human health risk costs, environmental costs, remedial action, potential back-up in the house, and other costs). These costs are difficult to estimate, as they are mostly social costs that depend on people and their values. Methods usually employed for this purpose are mentioned in Chapter 6, *Costing Principles*.

RME Realm of Responsibility and Control

Even at the Level 5 RME ownership model, decentralized wastewater management decisions are not solely in the hands of the RME. Indoor plumbing and fixtures are an important part of the decentralized wastewater system, and changes made indoors (for example, low-flow fixtures or separate paths for blackwater and greywater) can have significant effects on the rest of the system. RMEs may limit water use or provide water-conserving fixtures or incentives to customers as a demand-management measure. With all US EPA management models, least-cost optimization of decentralized wastewater assets will involve the interests of multiple parties.

Usually the homeowner owns the plumbing and on-lot components, and the RME controls from the road right-of-way (ROW) to the leachfield. When the entire system is to be upgraded onsite, or when the collection system includes an important component on the property (for example, septic tank, septic tank effluent pump, or grinder pump), the RME should either own these components or have the right to enter the property to construct, maintain, repair, or replace components.

1.2.3 Questions and Perspectives of Regulators

Regulators are interested in the medium- and long-term outcomes of investment in onsite system reliability. All types of system failures are likely to be of interest, both related to the system and with regard to effects on the whole watershed. The regulator may have use of any of the reliability tools in the table, although the regulator may have different or additional motivations for using them than the practitioner or RME.

- **Failure curves, cohort analysis, probability assessments, critical component analysis,** and **failure modes and effects analysis** may be used by the regulator to set or revise prescriptive guidelines about treatment system design, installation, or maintenance. **GIS-based tools** may be used to identify which systems have the highest potential environmental impact or (the other side of the coin) which water resources are most vulnerable to the impacts from the systems.
- **Systematic troubleshooting** on the part of practitioners may be encouraged by regulators as a way to improve service to system owners and to gather consistent data on system performance.
- **Process reliability** may be used to set performance standards as being required to be achieved 90% or 99% of the time, rather than all of the time, if that is consistent with protecting public health and the environment at a significant cost savings.
- **Statistical field sampling** of system performance is generally a multi-year project involving a team of five or more people and much up-front planning, intensive data collection, and detailed data analysis. Regulators (including policymakers) are the only audience likely to have the interest and resources to finance and set up such studies.

Regulators make decisions about the bigger picture: to protect public health and the environment, to reduce costs to society as a whole, and to define institutions that partition costs equitably across different parties. Regulatory and organizational structures define how and by whom the risks and costs of wastewater management will be borne. The costing tools important to regulators include **life-cycle costing** (to be able to compare systems), **risk-cost modeling** (to understand the severity and consequences of failure), and **cost-benefit analysis** (to compare different paths for the future).

Regulators may examine a range of potential scenarios that improve reliability and reduce risks of small wastewater systems. Many tools may be employed to compare different scenarios. These tools include:

- Modeling the effects of the options
- Cost modeling (including life-cycle costing) of different options
- Assessment against the desired goals or performance standards
- Cost-benefit analysis
- Cost-effectiveness analysis
- Economic impact assessment
- Equity assessment

Analysis may also involve integrated risk management (considering all different types of risks concurrently) and socio-economic risk assessment. Regulators may involve stakeholders in evaluating scenarios, since simple answers are rare and different parties have different views on the relative importance of various issues.

Integrated Resource Planning (IRP) should inform least-cost optimization for decentralized wastewater management. In IRP, the option with the lowest cost to the whole of society is determined, and then cost-benefit partitioning between different stakeholders is addressed to ensure that all parties gain by pursuing the least-cost option. For example, reduction in water demand (and therefore quantity of wastewater) may allow new growth to occur that would not be possible otherwise. Where water and wastewater utilities are collaborating under drought conditions, reduction in water demand reduces the need and expense of very deep wells (so perhaps fewer wells are needed) and allows for smaller, cheaper cluster systems to be built. Money saved by reducing wastewater treatment system capacity could partially offset the cost of the new wells.

For regulators, it will also be important to analyze who invests what. In the decentralized field, investments happen at a homeowner/property owner level, the municipality level (towns, villages, cities), the regional or county level, and the state and federal levels. Investment is not only at the owners' level. Consideration of all perspectives in economic analyses is needed to examine costs to each party. Diagrams of the different parties involved and how money is transferred between these parties and in and out of the "system" are another way to think inclusively about this issue, in addition to the costing tests described above.

1.2.4 Questions and Perspectives of Homeowners

The perspectives of homeowners are included to inform practitioners and other parties of homeowners' likely concerns with investing in the reliability of their onsite systems. Homeowners' perspectives give practitioners, RMEs, and regulators a basis for providing services that meet homeowners' needs at the lowest cost and with the least risk to humans and the environment.

Homeowners often enter discussions of onsite systems wanting trouble-free systems without any responsibility for their maintenance or for costs associated with maintenance or repair. (The initial perspective can change when costs of extending a sewer line are presented or the importance of system maintenance is tied to preserving water quality.) From this perspective, anything that increases system reliability without requiring extra effort or cost from the system owner is an improvement.

On the cost side, homeowners are likely to be interested in short-term investments and rewards. They may be interested in the medium-term if they plan to live in the same place for several years. Their cost perspective will generally include only their own perspective, unless they are part of a community management arrangement. Localized failure will be their greatest concern, including surfacing effluent, effluent backup, and odor. In addition, homeowners may be concerned about environmental damage and drinking water source protection.

Homeowners are likely to want answers to a range of questions concerning how they invest their money in system reliability. They will need information to help them determine whether it is worth paying more for a more reliable system, and what the benefits are. This requires life-cycle costing of the units they are considering. Life-cycle costing represents the only way to inform homeowners of the longer-term costs depending on their choice of system. They may be interested in whether it is more cost-effective to set up a maintenance contract or to wait until parts break or fail. They might want to understand whether there is benefit in installing risers and inspection ports to aid in system monitoring. Homeowners are unlikely to want to pay for their tank to be pumped needlessly.

The challenge for practitioners, RMEs, and regulators is to encourage desirable decisions and behavior from homeowners knowing the above perspectives and concerns. An example of an incentive that encourages homeowners to ensure system reliability is to have them pay for monitoring. If the system is functioning properly, monitoring frequency can be reduced from quarterly to annually, giving them a direct cost savings.

1.3 How to Use This Handbook

This handbook is intended to provide the reader with a solid foundation in all elements of system reliability. From early identification of challenges and goals for the infrastructure, through developing fully allocated cost systems and tools to improve the reliability and thus the longevity of the systems, this handbook will assist the decentralized system managers, local or state policymakers, practitioners, and ultimately homeowners. This handbook is not intended as a seminal work, nor is it intended to be exhaustive, or the final word. Rather, it is a solid introduction, with enough detail to get the reader started down the path of improving the performance of decentralized infrastructure both economically and environmentally.

The handbook is organized in two broad sections—framework and tools. The framework is designed to lead a community or jurisdiction through the initial decision-making process and to help it evaluate its progress over time. Parts of the framework include:

- The goal-setting process
- Understanding regulatory limitations
- The implications of socio-economic issues of local or state importance
- The alternatives
- Evaluating past decisions and outcomes

The tools provided in this handbook fall into two broad categories—costing tools and reliability tools. One tool provided is a mix of the two. The costing tools provided in the handbook are intended to enable the reader to carefully allocate the true costs of any solution or ongoing activity so that the best possible financial decision, considering matters of importance in the jurisdiction, may be made. The reliability tools enable the reader to consider how best to address issues such as meeting regulatory requirements, when to replace parts of systems, and where to invest in preventative maintenance. These tools can be applied to decentralized infrastructure servicing individual homes, cluster systems serving large volumes of users, or combinations of systems and jurisdictions aimed more at policy implementation.

The reader may be interested in one or both of these topics. Within the tools section, the reader may similarly be interested in all or some of the tools explained. Thus, use of this handbook is intended to fit the reader's needs. It may be read from cover to cover, but will more likely be used as a reference to answer specific questions.

Real-life examples and a fictional case study are interspersed throughout the document to assist the reader in further understanding the framework and tools. The supplementary materials are enclosed in different types of boxes, as shown below.

A box with a double-line border indicates a pertinent real-life example of the framework or tool. These examples are short and may only deal with part of the framework or a narrow part of a costing or reliability tool. However, they provide understanding of the issue and encouragement in that they represent proof that these ideas are being used in the industry today.

A shaded box alerts the reader to the case study that runs throughout the handbook. This case study is fictional, since no jurisdiction is currently using all of the tools. This case study is a mixture of real-life situations and pure fiction, and provides the reader with an illustration of what is possible if the framework and tools are all adopted in the same place.

Table 1-2
Overview of the Fictional Case Study "Jerry's Awakening"

Episode	Text Section
Jerry decides to investigate the asset management framework	2
Jerry analyzes the existing situation and goes to the first public meeting	4.3.3
Jerry and Valerie agree on performance standards	5.1
Data are digitized and analyzed with the help of GIS; 110 systems are selected for condition assessment	5.4.1
Jerry argues to Valerie that a nitrate standard should explicitly recognize process variability	5.6.1
Jerry and Valerie apply a version of risk-cost analysis to mounding potential	7.5.2
Conclusion	9

2 CASE STUDY: JERRY'S AWAKENING

As usual in the early fall, Jerry was dazzled by the rising sun and its reflection off the ocean when he opened his front door to pick up the morning newspaper off of the porch. Glancing at the headlines, he almost instantly forgot the bright beauty of the scene around him. The paper reported on page 1 that the Sandy Bay Environmental Alliance found high levels of fecal indicator bacteria in Fish Brook. A picture showed a volunteer wearing waders, scooping up a water sample, with houses right next to the brook in the background. For Jerry, the director of the Sandy Bay Wastewater Dispersal Zone, the story was going to mean a lot more questions about the state of the two thousand decentralized wastewater treatment systems his company was responsible for. Jerry took the paper in to the breakfast table, poured himself a cup of coffee, and sat down to study the article more closely.

The Sandy Bay Wastewater Dispersal Zone, or "The Zone" as most residents knew it, was a privately-owned utility with responsibility for all of the decentralized wastewater treatment systems in the area of Coastal County near Sandy Bay. Almost every property in the area got municipal water, and the downtown region of Sandy Bay was connected to a centralized wastewater treatment plant. Most of the remaining properties had onsite wastewater treatment systems. Some were attached to cluster systems, with primary treatment taking place in a septic tank on each property; a small diameter sewer carried the water to another site for further treatment and dispersal. The Zone was responsible for both the onsite systems and the cluster systems.

The finding of high levels of indicator bacteria in Fish Brook was only the latest instance of water quality concerns that the Sandy Bay Environmental Alliance (SBEA) had brought up or helped highlight this summer. The state's environmental agency closed the shellfisheries off Sandy Bay for a month earlier in the summer, when high levels of indicator bacteria were found there. SBEA volunteers scuba dove to the shell fisheries in August and found dead zones, hypoxia, on their edges, where the water had too little oxygen to support fish life. On top of that, SBEA conducted weekly monitoring of water quality at Big Bay Beach—a tremendously popular destination for both locals and tourists—all summer, and six times found levels of fecal coliform bacteria that exceeded the state's recommendations for swimming waters. The warning signs the city posted were a real damper on the spirits of the residents and discouraged visitors from coming to Sandy Beach.

This rash of publicity led to a threat to The Zone's continued existence: A group of residents formed to demand an extension of the sewer to everywhere The Zone served. They were talking to City Council members and the mayor, trying to schedule hearings on a sewer extension.

Jerry did not think that a sewer extension was likely. He knew that the wastewater treatment plant operated at over 90% of capacity now, and that any request for increased capacity was likely to be turned down by the state. Still, he knew that the latest SBEA finding was likely to increase pressure for extending the sewer, which meant more of his time would be spent in meetings about a sewer and defending The Zone's management.

As Jerry finished breakfast and put aside the paper, he considered his response to the inevitable phone calls about the article and how he would continue to defend The Zone's management. He realized that he had a harder time than he liked in responding to the critics. A quarter of the onsite systems The Zone managed were twenty years old or older, and quite a few were over fifty years old. The older ones were built before today's design and installation rules, and many of those had leachfields close to the water, or where the groundwater was shallow, or both. State Board of Health regulations allowed these systems to continue to be used under a grandfather clause, which made things easier for Jerry's day-to-day management of them, but made it harder to manage strategically in a way that minimized the environmental impacts of the onsite systems. After all, one leachfield in direct connection to surface water could discharge a lot of bacteria and viruses into the water.

When he got to work, Jerry decided to call his friend Jim, who moved to Sandy Bay after retiring from a career with the US EPA, to see if Jim could give him any new thoughts on how to defend The Zone's management or how to do things differently. Jim agreed to have lunch with him later in the week.

Over lunch, Jerry told Jim his latest thoughts on the discussion of whether to extend the sewer in Sandy Bay. "Sure, high levels of fecal coliform were found at Big Bay Beach and in Fish Brook," said a somewhat exasperated Jerry, "but who knows whether they were from our wastewater treatment systems, from storm water, or even from cows or wildlife? Resident flocks of geese and seagulls could be contributing most of the coliform, or dog feces washed into the water by rain—shouldn't we put in place a pooper-scooper law at least before starting to talk about sewering?"

Jim nodded. "Sure, all the fecal coliform test showed was that feces from some mammal entered the water. A study in Vermont found exceedances of EPA swimming water standards in pristine watersheds after rains—beavers were tagged as the 'offending' creatures! I think you're on solid ground when you make that point. Still, your best PR strategy is to be more proactive than just pointing a finger at someone else. A lot of people know that The Zone manages onsite systems built to outdated standards, on marginal sites, near the water. If you're seen as stonewalling attempts to improve the treatment at these sites, you're not going to win a lot of friends. And think about the new subdivisions planned just outside of town. They're going to use onsite or cluster systems, and The Zone could get the contract to manage them. You're not going to improve your chances of taking on the new systems by fighting a rearguard battle about the systems you already have."

Jerry saw the point and grunted grudging agreement. "So you think I should spend a lot of money to replace lots of onsite systems with cluster systems, even though none of the existing systems may be causing a problem?"

"No, that's not necessarily what I mean," Jim assured him. "Maybe an offsite solution like cluster systems is the best thing for these older systems. Maybe it's not. The point is to find out whether that's the case, and expend your investment wisely."

"So how do I do that? Get someone to do one of those tests to see where the fecal coliforms are coming from?"

"That would be one place to start," replied Jim, "but not necessarily the best. The tests are expensive, take a fair amount of time, and are not necessarily conclusive. And even if the results came back that the fecal coliforms aren't from humans, where would that leave you? Some pressure would be off you, but you'd still have a lot of aging systems that people are suspicious of. They'll say that the systems need to be replaced by sewer before they start causing problems in the future."

"OK then, where would you suggest I start?"

"Well, you need to find out how your systems are performing. Also, you're facing a situation where you *might* be replacing a lot of existing systems—depending on what you find out about their performance. Do you have money for that?"

"In a word, no. Most of our income comes from monthly user fees," explained Jerry. "The fees have been set assuming we wouldn't be replacing a lot of the older systems, since they're grandfathered in."

"Sure. So you need to figure out the scope of any new investment you might be making and build a case for it. At the same time, you need to build a case that you've been spending all your resources effectively. Getting a rate increase approved is never easy, and you need to be able to clearly document how you've been trying to squeeze the most out of you're existing resources. Here's something that might interest you: The US EPA has been offering a series of asset management workshops around the country for centralized water and wastewater utilities. I bet you could apply many of the same principles to The Zone. Why don't you sign up for one of those and see if the asset management principles could be used in your company? And pay a visit to Valerie at the Natural Resources Department, to let her know what you're thinking. She may have some resources to help."

Their meal came, and as they ate it, Jim told Jerry more about asset management and how it helped utilities save money and improve service. Jerry was intrigued and agreed to look into asset management and to visit Valerie.

The Case Study continues on page 4-6…

3 ASSET MANAGEMENT IN CENTRALIZED AND DECENTRALIZED SYSTEMS

Asset management is based on a simple idea: Find out what a utility's assets are, where they are, what condition they are in, and how they affect the utility's ability to meet performance requirements; then use this information to make decisions about investing in new assets and maintaining existing ones. Asset management has been used in centralized water and wastewater utilities for more than 15 years in Australia, New Zealand, and the United Kingdom, and more recently in the United States.

The Association of Metropolitan Sewerage Agencies (AMSA) handbook describes asset management as "an integrative optimization process that enables a utility to determine how to minimize the total life-cycle cost of owning and operating infrastructure assets while continuously delivering the service levels that customers desire" (AMSA Undated). Asset management for centralized urban water uses information systems to characterize risks associated with failure to repair or replace particular infrastructure components and a decision-making approach that uses risk assessment to measure benefits of alternative approaches to infrastructure maintenance, rehabilitation, and replacement.

3.1 Asset Management in Centralized Urban Water: Concepts, Frameworks, and Methods

In the centralized water and wastewater utility sector, four key elements are critical to successful asset management systems:

- Service and performance standards
- Asset information systems: asset inventories, databases, asset monitoring, and Geographic Information Systems (GIS)
- Tools for reliability analysis and life-cycle costing, including estimates of asset condition, useful-life, and the cost of asset operation, maintenance, rehabilitation, and replacement
- A regulatory and organizational structure conducive to least-cost financial optimization. (Asset management is ordinarily used where ownership and decision-making are substantially in the same organization. This handbook will apply asset management in other institutional contexts.)

Each of the key elements is discussed in turn.

3.1.1 Performance Goals and Standards

Performance goals and standards answer the question, "What are we trying to achieve by managing these assets?" They are largely driven by the service expectations of customers and other stakeholders. In the AMSA handbook, performance standards and goals are discussed in terms of "strategy" and in terms of a utility developing objectives and policies in consultation with customers that frame performance standards for assets. For example, a standard may be set for a maximum number and duration of water shutoffs that customers can expect to experience during a year. Alternatively, the policy may be one of continuous improvement in service continuity or maintaining asset condition (Young 2002). In other jurisdictions, regulators mandate performance standards in operating licenses (Young and Belz 2003). The regulator, acting as a proxy for other stakeholders, can play a strong role in asset management by setting unambiguous performance standards that the utility must meet. Asset performance standards may be set for environmental outcomes (Astley and Hopkinson 2002) as well as the more commonly considered outcomes including potable water quality, service provision (supply continuity and avoidance of on-property sewer overflows), and level of customer service.

3.1.2 Asset Information Systems

Asset management requires an information system that tracks assets, how they are managed, their costs, and reliability under that management (AMSA Undated). Central to the information system is an inventory of assets, which covers at least the location, condition, and criticality of each asset. An accurate asset inventory sets the stage for effective management (WERF 2002). Keeping the asset inventory up-to-date is essential. Monitoring and condition assessment enable this, as well as providing a way of checking for failure. Condition assessment involves assessing the overall structure and function of the system through visual (and olfactory) inspection, and may also involve tests like dye tests or running a large amount of water through the system. Condition assessment helps set appropriate maintenance and repair schedules, so that a utility knows when assets are failing and/or requiring repair. Monitoring of measurable parameters, like dissolved oxygen content of the water, depth of sludge in a septic tank, or number of pump cycles, can be made through periodic visits or continuously, through telemetry.

3.1.3 Reliability Analysis and Life-Cycle Cost Tools

The reliability of pipe networks has claimed major attention in asset management for centralized water and wastewater systems. Pipes for water distribution and wastewater conveyance represent important assets for centralized utilities, and pipe breakage represents a risk of significant consequence. The potential for pipe failure can be assessed through both technical reliability analysis and asset inventory analysis. Ostfeld (2001) describes a stochastic simulation for reliability analysis of distribution assets. Fenner *et al.* (1999), Babovic *et al.* (2002), and Silinis *et al.* (2003) describe various approaches to analysis of asset inventory information (and in the case of Silinis *et al.*, biophysical data such as soil type) to group assets into classes and to assess failure risk based on previous experience.

Various cost-risk models such as those described by Young and Belz (2003) and CSIRO Urban Water (2003) were developed for asset management in centralized water and wastewater. These models identify optimal pipe maintenance and replacement strategies based on life-cycle cost, with reliability analyses used to estimate the risk of pipe failure under various management scenarios. A utility may decide to replace a pipe before it bursts if replacement avoids the risk of expensive consequences. Alternatively, the utility may calculate that it makes financial sense not to replace some aging pipes and that performance goals can be met at least cost by waiting for pipes to burst before they are replaced.

Similar reasoning and similar tools are applied to pump stations, treatment plants, and other assets owned by centralized water and wastewater utilities.

3.1.4 Organizational and Regulatory Structures

The classic form of asset management occurs within an economically regulated[3] utility that owns and manages its own assets. Motivated by financial interest and applying a corporate accounting standard, the corporation manages assets to meet agreed performance standards at the least life-cycle cost to the corporation. This approach involves balancing the operation, maintenance, rehabilitation, and replacement costs of assets together with the risk and consequence of not meeting performance standards (Young and Belz 2003). The Australian urban water sector provides an example of the importance of regulatory and organizational structures in promoting asset management. Asset management came to the fore in the water industry in Australia after the commercialization of utilities and clear delineation of the role of environmental regulators. Where other organizational structures exist in urban water, asset management remains possible; some business process redesign may be necessary to promote the least-cost optimization of managed assets (AMSA Undated).

3.2 Differences Between Centralized and Decentralized Wastewater Management

Asset management in centralized and decentralized wastewater treatment has a common goal: to install and manage systems that deliver the lowest life-cycle cost to treat water to the extent necessary to preserve and/or improve the quality of groundwater and surface water resources, plus meet any other applicable performance standards.

There are differences in what aspects of the systems are most significant to meet that common goal. Wastewater collection costs dominate the life-cycle cost of centralized wastewater systems (AMSA Undated). For decentralized wastewater management, the treatment process itself is of greater importance to total cost, and dispersal is a major factor for onsite systems.

Together with the differences in relative importance of pipes and treatment to system performance, managing decentralized wastewater systems involves special challenges not found in centralized wastewater collection and treatment. Important differences between centralized

[3] Unless otherwise noted, references to regulators and regulations in this handbook are to environmental and health regulators and regulations.

and decentralized wastewater systems from the perspective of asset management are presented in Table 3-1. Managing decentralized systems includes the issues of siting, the impacts of varying usage, a need for effluent data, and the multi-faceted nature of risks from system failure. Like the systems themselves, ownership of the systems is generally dispersed. Usually, no single organization coordinates investment decisions for decentralized wastewater infrastructure, though local regulators and policymakers may use financial incentives, regulations, and penalties to encourage system owners to manage their systems in specific ways. While management and possibly ownership of decentralized systems by responsible management entities (RMEs) would increase the parallels to the management of centralized systems (US EPA 2003a), few systems today are controlled by such entities.

Table 3-1
Relevant Management Issues for Centralized and Decentralized Wastewater

Management Issue	Relevant to Centralized Systems?	Relevant to Decentralized Systems?
Quality of site is critical	Unusual	Normal
Performance of pipes is critical	Normal	Normal (but pipes are generally short)
Performance of treatment systems is critical	Normal	Normal (for pre-treatment, before dispersal)
Performance of soil-based treatment is critical	Unusual	Normal (except for larger systems)
Performance of wastewater dispersal systems is critical	Unusual	Normal
High flow variability	Normal	Normal
Lack of effluent data	Unusual	Normal
Dispersed ownership and operational responsibility	Unusual	Normal
Regulations addressing management, operation, and maintenance	Normal	Unusual (except for larger systems)
Poor understanding of maintenance requirements from the asset owner	Unusual	Normal
Probability that individual asset failure will go undetected	Unusual	Occasional - Normal
Potentially high consequence of individual technical failure	Normal	Unusual

Another key difference between decentralized and centralized wastewater systems is the complexity with regard to risk, which is a key determinant of the required level of technical reliability of a decentralized system and its various components. As mentioned earlier, centralized systems have the risk of pipe breakage as a primary risk, and this risk is normally acute with potentially high consequences (for example, flooding of residences or closing of high-use roads while repair occurs). It is therefore important to keep the probability of such a consequence occurring very low. In contrast, decentralized systems have a wider range of critical modes of failure with a large range of possible consequences, mostly of much lower impact than for centralized systems. Keeping the probability of failure very low then, is not as critical in this instance as in the centralized case.

Many of the impacts of decentralized asset failure are chronic in nature and cumulative over time, although acute impacts are also possible. Jones *et al.* (2000) categorizes four types of risks associated with decentralized systems: engineering, public health, ecological, and socio-economic risks. This risk profile is broader than a focus on engineering or technical reliability. It makes asset management more complex and underscores the importance of understanding risk for decentralized systems. Reliability analysis tools for decentralized systems need to include various types of risk- and impact-assessment tools. In addition, as decentralized systems are often operated and maintained by homeowners, reliability analysis must account for their probable actions and ways of influencing their actions.

3.3 Asset Management for Decentralized Wastewater Systems

Asset management for centralized water infrastructure was developed through a painstaking, fifteen-year process of discussion and discovery, with much of the work done in Australia and New Zealand. Some major US utilities (for example, in Orange County, CA; Seattle; Boston) have adopted asset management, often using consultants from Australian utilities. Roger Byrne, who has worked as an advisor on asset management to utilities both in Australia and the US, says that US utilities can avoid many of the mistakes of the Australian utilities and make use of many of the tools they developed (Byrne 2004). The prospects for quick transfer of asset management to other sectors, like decentralized wastewater, are also good, Byrne believes. While new data must be gathered for reliability of key components, many tools can be adopted or adapted across sector boundaries. For example, an information system now being used in water utilities originated in the steel industry[4].

This section describes how three of the four key elements of asset management in centralized urban water might be applied to decentralized wastewater, taking into account the differences described above. The fourth element, tools for reliability analysis and life cycle costing, is covered in Chapters 5 and 7.

3.3.1 Performance Goals and Standards

Performance standards answer the question, "What are we trying to achieve by managing these assets?"

[4] Ivara EXP (http://www.ivara.com/main.php?tID=1&lID=1)

Prescriptive and Performance-Based Regulations

Regulations governing onsite wastewater treatment systems typically focus on site selection, sizing, design, and treatment system installation. Clear instructions, or prescriptions, are given to implement these regulations. Regulators, designers, and installers find it relatively easy to know whether a given system is in compliance with these regulations.

The main disadvantage of prescriptive regulations is that it is more difficult for technological innovation to occur. New types of wastewater treatment technology must be specifically accepted by each state or local jurisdiction that uses prescriptive regulations. This can be a long, expensive, and cumbersome process.

Performance-based regulations describe clear, measurable conditions or outputs that processes or components are to achieve. These performance standards allow multiple solutions: any technology that can meet the performance standard is permitted, and new types of technology can be incorporated into regulations more easily as they come along.

Disadvantages of performance-based regulations include greater complexity in the design and installation process, which increases workload and risk for engineers, installers, and regulators.

For decentralized wastewater treatment, some general performance standards apply almost anywhere. A far from exhaustive list includes:

- No surfacing of effluent from soil absorption systems
- No strong, unpleasant odors
- Enough treatment before the effluent reaches drinking water sources so that the drinking water meets Safe Drinking Water Act standards
- No significant impacts on nutrient status of nearby waters
- Large reductions in pathogen levels before human contact with effluent

Some places have additional, local standards, for example:

- Total nitrogen in effluent no more than 3 mg/L (Ayres Associates 2000)
- Phosphorus in effluent no more than 1 mg/L (Ayres Associates 2000)
- Seventy-five percent of the phosphorus is to be recycled in agriculture (Ridderstolpe 1999)

Additional examples of performance standards are listed in Section 5.1.

In industries using asset management, regulators play a crucial role both in setting the performance standards and in setting who is responsible for meeting the performance standards. In decentralized wastewater treatment, most regulations are prescriptive, rather than performance-based. Performance-based regulations give more latitude to apply asset management strategies, as a greater range of technical options is available (see text box on this page). If the efforts of the National Onsite Wastewater Recycling Association (NOWRA) to develop a performance-based model code (NOWRA 2004) lead to greater use of performance standards by state and local jurisdictions, then asset management will become easier to apply to decentralized wastewater treatment.

Implicit in setting performance standards is a definition of system boundaries. For example, in decentralized wastewater treatment, the system may be defined as the installed collection and treatment system, and thus requirements will be set on its performance at the point the treated effluent leaves the engineered system (including the soil profile characterized during system design, if a soil absorption system is used) and until the solids reach the final place humans move them (such as a landfill or agricultural field). This definition excludes any performance standards on the public health or environmental impacts from manufacturing or construction processes. For example, in a cradle-to-grave environmental life-cycle assessment, performance standards could be set for the embodied energy and greenhouse gas implications of the septic tank material of construction (for more information on environmental life-cycle assessment and wastewater treatment, see Kirk *et al.* 2005).

3.3.2 Asset Information Systems

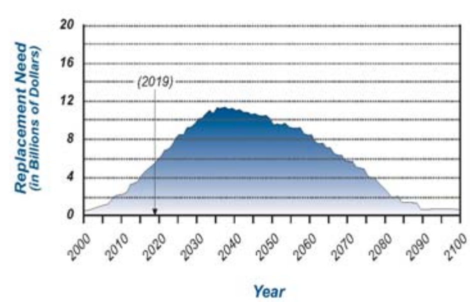
The information system necessary for decentralized systems will need to contain a variety of information. The detail and diversity of information stored in such a system may vary considerably. A database may include such information as:

- An asset inventory (system type, age, location, capacity/scale/design flow, maintenance history)
- Ongoing performance information (site condition assessments, monitoring, loading rates)
- Biophysical information (planning/land use, lot size/density, soil, wetness, slope, water courses, vegetation, watershed characteristics)
- Data on expected reliability of systems and components
- Cost data for capital works and operations (historical cost of capital, operation, and maintenance)

An understanding of what affects asset performance is used to translate inventory information into useful predictions about the cost of various strategies for maintaining performance. In an onsite system, telemetry may indicate that a pump is cycling more (or less) often than it is expected to, showing that

Nessie Curves

A “Nessie” curve is a graph of the annual asset repair and replacement needs for existing infrastructure such as a pipe network or the set of all utility assets. It is based on when the assets (for example, pipes) were installed and how long they are expected to last before it is economically efficient to replace them together with estimates of refurbishment and replacement cost (AWWA 2001). The Nessie curve enables a utility to understand the scope and nature of the future infrastructure or asset cost requirements. The history of pipe network installation by water and wastewater utilities in most cities in the industrialized world means that these curves of estimated future costs are seen to rise in a wave shape over the next half-century. This rising wave shape gives these curves their name, after the Loch Ness monster.



(US EPA 2002)

Figure 3-1
Nessie Curve Showing Pipe Replacement Need Estimates Over the Next 100 Years

US Environmental Protection Agency's Voluntary Management Models

Model 1: The Homeowner Awareness Model

- Ensures systems are sited, designed, and constructed in compliance with prevailing rules
- Includes inventory and documentation of all systems by the regulatory authority, with voluntary maintenance

Model 2: The Maintenance Contract Model

- Builds on model 1 by ensuring that property owners maintain maintenance contracts with trained operators
- Includes tracking and reporting functions to ensure that requirements of maintenance contracts are fulfilled

Model 3: The Operating Permit Model

- Builds on model 2 (The Maintenance Contract Model) by issuing limited-term renewable operating permits to individual system owners
- Provides continued oversight of system performance (may include scheduled inspections)

Model 4: The Responsible Management Entity (RME) Operation and Maintenance Model

- Similar to model 3, except that after systems are constructed, operating permits are issued to a management entity that performs operation and maintenance activities. The RME charges owners a fee for operation and maintenance of outdoor fixtures, but has no authority over indoor plumbing.

Model 5: The Responsible Management Entity (RME) Ownership Model

- Similar to model 3, except the RME owns, operates, and manages the decentralized wastewater treatment systems in a manner analogous to centralized treatment. The RME charges owners a fee for operation and maintenance of outdoor fixtures, but has no authority over indoor plumbing.

the system is operating outside its design specifications. This is a clear signal that the performance of the system has dropped or is about to drop. A manager's experience may give him a good idea about how performance is dropping and what the consequences may be for the rest of the wastewater treatment system, public health, the environment, and the people near the system. That information can be used to decide how to prioritize attention to the system with the abnormally cycling pump.

Databases specifying component reliability under given circumstances can be used to explore the consequences, including financial costs, of various management strategies. For a long-term view of infrastructure replacement needs, a database with information on asset condition, reliability, and rates of renewal and replacement can be used to generate "Nessie curves" (see text box on previous page) showing how well rate of renewal and replacement matches the anticipated rate of deterioration over many decades to come.

3.3.3 Organizational and Regulatory Structures

In decentralized wastewater treatment, the corporate model is only seen in the small number of cases of management at model 5 of the US EPA voluntary management guidelines (US EPA 2003b), where an RME owns the collection and treatment assets and is responsible for meeting all permit requirements. A model 5 RME has obvious interests in improving performance and optimizing assets. Not only must the RME consider the long-term view for the assets managed, but also have an interest in improving their performance to help cover rising salary and labor costs to avoid rate increases.

Management models 4 and 5 are infrequently used today. Much more frequently found are maintenance management entities. They do not own the infrastructure; they may or may not have contracts with the homeowners for regular maintenance; and they do not have responsibility for operating permits. These companies do not, by themselves, comprise any of the EPA models, though they play a significant role in models 1-3.

Organizational and regulatory structure plays such a significant role in wastewater asset management because the structure defines how and by whom the risks and costs of wastewater management will be borne. For example, maintenance management entities have a different set of incentives than utilities. Regulated utilities are guaranteed a return that is equal to or greater than their documented costs. (Income is determined in part by the rate system permitted by the public service commission (PSC), which also scrutinizes utilities' cost-reduction measures.) Maintenance management entities can make money on every repair, upgrade, or modification (like installing access risers), whether or not it is in the long-term financial interest of the system owner. On the other hand, if the maintenance management entity is competing with other entities—or with a homeowner's potential choice to neglect maintenance—then it is very much in the company's interest to find and use cost-effective maintenance techniques and pass the cost savings on to the customer.

The role of an asset manager in deciding on the appropriate response for a given decentralized system is often taken on by a local regulatory body, typically the local or state health department. These local regulators are charged with protecting public health and the environment. They can apply asset management to determine how to protect public health and the environment at the lowest long-term cost, information that can strongly influence their decisions. However, the regulators' decisions can normally only be put into effect by the asset owners (that is, the homeowners) complying with the conditions.

Integrated Resource Planning (IRP) and the methods for considering demand management measures offer a way to consider alternative financial system boundaries or cost perspectives. Moving towards least-cost optimization for such decentralized wastewater management situations will require a similar approach. IRP and the methods for considering demand management measures offer something of a model.

Cost perspectives are important in water and energy IRP because demand management is commonly the least-cost option for meeting growth in demand for utility supplies from a "whole of society perspective," yet conserving water can result in a reduction of revenues to the utility (White and Fane 2002). Alternative cost perspectives are used to address the issue of cost-benefit partitioning to enable both utilities and customers to gain from pursuing the least-cost option.

The life-cycle costing tools used in asset management of decentralized wastewater should reflect the nature of the various organizational and regulatory structures of decentralized system management.

4 A FRAMEWORK FOR ASSET AND RISK MANAGEMENT IN DECENTRALIZED WASTEWATER TREATMENT SYSTEMS

The framework for asset and risk management will guide handbook users to the tools best suited to help them manage the reliability and cost of their particular decentralized wastewater treatment systems. The framework provides a step-by-step process, alerting users to different issues they will need to consider and directing them to an appropriate set of tools that can assist in optimal management of decentralized wastewater treatment assets.

The framework provides a generic process applicable to most situations, though three points must qualify this statement. Real-life situations do not always occur in simple, logical steps, and some aspects of the process may have already occurred when a user picks up the handbook. Iteration of some steps may be required before further steps can be completed. Different tools will be applicable in different US EPA management models, and some tools will be applicable differently depending on the US EPA management model (see Section 3.3.3 and the associated text box outline of the EPA management models).

4.1 Framework Background

The framework was synthesized from a review of literature and practice in the fields of asset management, reliability and risk assessment/management, and decentralized wastewater management. The framework was designed to parallel existing asset management initiatives in the centralized field. However, the relative complexity of multiple stakeholders and diverse risks in decentralized wastewater management requires significant adaptation in how the framework is applied. Reliability and cost tools are only relevant to asset management of decentralized systems within a context that recognizes when, where, and how these tools are needed. The framework attempts to provide that context.

The framework incorporates aspects of asset management and risk assessment, and it reflects:

- A step-by-step process for the user that may be applied through one or more iterations
- The central place of the information system, which is added to and accessed in the different steps of the process as needed
- The key role of communication with stakeholders, which is important for almost all steps of the process

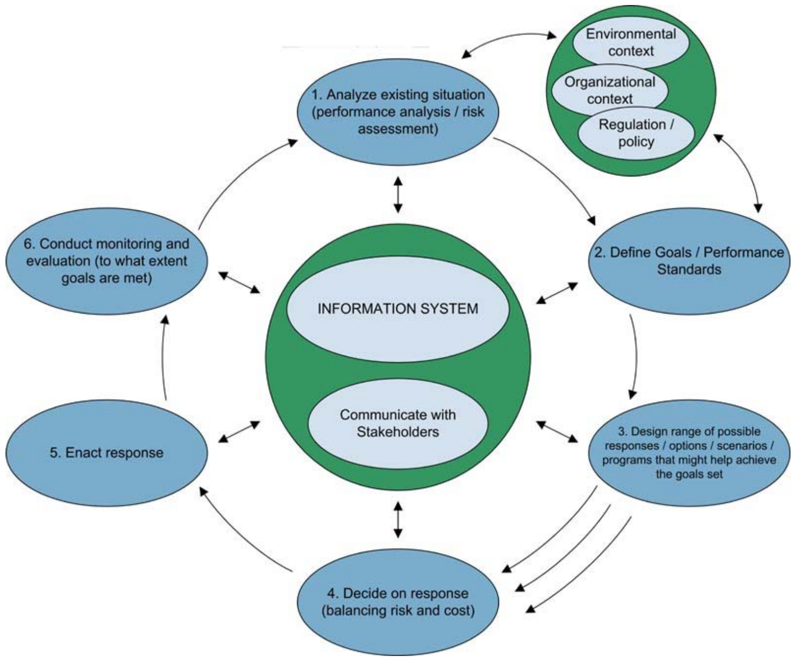


Figure 4-1
Generic Asset and Risk Management for Decentralized Wastewater Treatment Systems

4.2 Framework Steps and Tools

Here is how the framework (Figure 4-1) can be applied, with a step-by-step guide.

Step 1. Analyze Existing Situation – Performance Analysis / Risk Assessment

In this step, the situation is assessed, including environmental constraints, the regulatory and policy context, the organizational context, and an inventory of the decentralized systems as they are currently operating. This assessment pinpoints the risks and constraint so they can be used in defining appropriate goals and performance standards. The risks to be considered in this assessment are engineering and reliability, ecological, public health, and socio-economic risks at both the micro (immediate vicinity of a system or set of systems) and macro (watershed or region) scales. A mix of quantitative or qualitative procedures may be necessary, depending on the situation and the level of data available. The information system is used to calculate the current and projected future performance of the systems under the current user/operational practice, as far as is possible with the data available at this point in the process. The user assesses the status quo, identifies needs, and sets the stage for defining appropriate goals.

In this step, the reliability tools presented in Chapter 5 are among those used.

Step 2. Define Goals / Performance Standards

The goals and performance standards are based on the findings of the assessment made in Step 1 and take into account the environmental constraints, the regulatory and policy context, the organizational context, the current and projected performance of the systems, and the views of stakeholders. Agreement needs to be reached with all stakeholders on performance standards and on customer service goals that address the appropriate engineering, environmental, and socio-economic factors.

Step 3. Design a Range of Possible Responses / Options / Scenarios / Programs

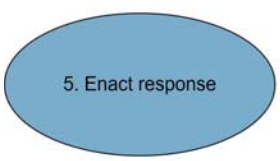
In Step 3, different possible ways to reach the desired goals and performance standards are articulated and explored. Benefits and costs of each potential response are described. Consultant input is generally used for this step.

Step 4. Decide on Response (Balancing Risk and Cost)

Step 4 might also be called options assessment. The aim is to make a decision between the different options articulated in Step 3. It will involve modeling the effects of the options, cost modeling (including life-cycle costing) of different options, and assessment against the desired goals and performance standards from Step 2. It may also involve integrated risk assessment (considering all different types of risks concurrently), organizational risk assessment, and/or socio-economic risk assessment. This step can involve stakeholders in evaluating the proposed options against the goals/performance standards, as simple answers may not be apparent and different parties are likely to have different views on the relative importance of various issues.

The life-cycle costing tools presented in Section 7.1 are among those used in this step.

Step 5. Enact Chosen Response



While the response decided upon in Step 4 is being implemented, criteria need to be set at both the system and organizational levels for the monitoring necessary to determine the performance level of systems and potential impacts. An evaluation of the chosen response and its implementation against the goals/performance standards also needs to be planned.

Step 6. Conduct Monitoring and Evaluation

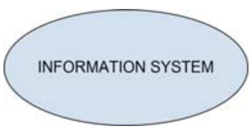
In management driven by performance standards, a recurring question is whether the standards are being met. Monitoring is performed on an ongoing basis, and evaluation is conducted periodically to see whether performance standards are met. When Step 1 is revisited, the user will have information that is current and more detailed.

Both the reliability tools presented in Chapter 5 and the life-cycle costing tools presented in Section 7.1 are among those used in this step.

4.3 Other Elements in the Framework

Two elements central to all the steps in the framework are information systems and communication with stakeholders. There are three contextual elements that influence the early steps in the framework: the biophysical environment, the organization, and the regulatory and policy context. These central and contextual elements are described in detail below.

4.3.1 Information System



The information system is a database that includes information such as:

- An asset inventory (system type, age, location, capacity/scale/design flow, maintenance history)
- Ongoing performance information (site condition assessments, monitoring, loading rates)
- Biophysical information (planning/land use, lot size/density soil, aspect, wetness, slope, water courses, vegetation, watershed properties)
- Data on expected reliability of systems and components
- Cost data for capital works and operations (historical cost of capital and operations and maintenance)

4.3.2 Communication With Stakeholders

The disaggregated nature of decentralized systems presents challenges, because many different parties are involved in their use and operation. Designers, manufacturers, homeowners, installers, managers, inspectors, and regulators all play a role. In addition, since impacts from such systems directly affect other parties, such as neighbors or other community members, the circle of stakeholders for these systems widens further. Gaining the cooperation and support of many or all of these stakeholders can be crucial to the success or failure of managing decentralized wastewater treatment assets.

4.3.3 External Drivers

Environmental Context

The natural environment constrains the type of decentralized system that may be safely operated in a particular region. Thus, environmental factors must be entered into the information system and considered in the initial steps of situation analysis and definition of goals and performance standards.

Organizational Context

The organizational structure plays a significant part in defining how and by whom the risks and costs of decentralized systems are borne. Who is responsible for ensuring that the systems meet performance standards? The details of how this question is answered provide a context for the analysis of the existing situation and the definition of goals.

Regulatory and Policy Context

The regulatory and policy context includes requirements for individual and cluster systems plus watershed-wide guidelines that need to be taken into account.

Application in a Centralized Utility: Seattle Public Utilities

Seattle Public Utilities (SPU), located in Seattle, Washington, operates the distribution and collection systems of the region's centralized wastewater, storm water, water, and electric systems. They are also starting to experiment with decentralized solutions for storm water services. In 2002, SPU began using asset management to ensure that funds were allocated to projects of critical system-wide importance.

Linking the environmental and public health risks of pipe failure is a critical element of SPU's asset management approach. By understanding the age and current condition of pipes and matching that information with risk, SPU has been able to cancel projects altogether, dramatically modify other projects, and advance other projects not previously deemed important. SPU greatly reduced its project backlog and its capital cost backlog, resulting in greater user fee stability and improved service. SPU has also begun to consider the role of decentralized solutions in their alternatives analysis process, and is currently evaluating the use of decentralized storage cisterns as part of the storm water system. The cisterns are located on private property and contain precipitation during storm events, enhancing the overall hydrology of the stream and river systems. The cisterns also allow settling, further enhancing water quality in the region.

SPU has a thorough project initiation and decision-making process. Goals are set, detailed analyses of projected results and overall risks are developed, and a panel of decision makers gauge the project's value against organizational and societal goals. Within this process, tools such as life-cycle costing, activity-based costing, risk-cost method, failure curves, and process reliability are used to ensure the most cost-effective and reliable solution.

SPU found little to no data with which to begin the reliability analysis, so they developed initial estimated data and analysis curves based upon their experience and computer models (Weibull curves). In the future, they intend to modify the Weibull curves to better reflect their experiences. Examples of SPU's use of reliability and costing tools are provided in Sections 5.4 and 7.5.

As luck had it, the next asset management workshop was the following week. Jerry managed to get one of the last places in the workshop, and traveled to Georgia to attend. Before leaving, he scheduled a meeting with Valerie for the following Monday.

Excited by the asset management framework and full of thoughts on how to apply it to The Zone, Jerry walked into the Natural Resources Department (NRD) office to meet Valerie, who had responsibility for coastal water quality protection. He sat down in Valerie's office and, after they exchanged pleasantries about their summers, Jerry recounted the latest activity of what he called the Sandy Bay Sewer-Everything-Now Coalition. He explained how he planned to be proactive in addressing effectiveness of all the decentralized systems he managed using asset management, and pointed out that he seemed to be a pioneer in applying this approach to decentralized systems. "I'm here," said Jerry, "to see what ideas you have to help me do the best job I can with this, and whether you have any money to help out in the effort. This is going to demand a lot of time from me and other Zone employees, and we'll probably need to get some help from someone experienced in a process like this."

"Sounds like you're full of energy and good ideas," Valerie said. "Money is tighter than ever in our department, but I have some ideas about how we might be able to direct some resources your way. Our senior senator managed to secure some funding for coastal protection that could plausibly be used to help you. There's one big impediment I see, though, to your work being effective, and for me being able to allocate these funds to you: you need to work with the citizens of Sandy Bay more. You've got to start calling people who have genuine concern about water quality something more respectful than the 'Sewer-Everything-Now Coalition.' You need to listen to them, have a candid exchange of views, and ideally get their buy-in for whatever you plan to do."

"You want me to get the Sewer…ah, these people, to agree with me before I do anything?" asked Jerry incredulously.

"Not necessarily on what actions you're ultimately going to take," smiled Valerie, "but more on the way you'll decide on those actions. As I understand your approach, you're trying to set up a process to decide on those actions, right?" Jerry nodded. "So tell the good citizens of Sandy Bay what you hope to accomplish in this project, and see if they think that's useful. If so, then tell them how you hope to accomplish it, and let them suggest ways to improve the plan. Look, you're undertaking this project to try to make sure that the wastewater treatment systems you manage are protecting the water quality and people aren't getting sick from them. That goal will win you friends. On the other hand, whatever you decide is the most effective way to do that, you're probably looking at a rate increase to fund the work. That's not going to win you friends. The rate increase will be an easier pill for people to swallow, however, if you have a significant number of active citizens who have endorsed the process you're using to make decisions and if you bring them along with you throughout that process. Otherwise, you end up with a plan that makes sense to you, but the people you ask to pay for it just say, 'Where did that come from?'"

Jerry saw the logic in this approach. He told Valerie that it sounded like a different sort of public meeting process than he was used to, where decisions were largely just explained after they had been made, and wondered if she or one of her staff would be available to help him implement the process. Valerie thought he would probably need more help than the Natural Resources Department would be prepared to give, and suggested that part of the funding be used to get assistance from someone experienced in stakeholder communication. He was paying close attention to everything she said about funding and readily agreed to this suggestion. Valerie gave him a copy of a handbook that suggested how to apply asset management and reliability tools to decentralized wastewater, and they agreed to work over the coming weeks to write a proposal to fund The Zone for its work.

(Continued on next page)

Jerry saw that the framework in the decentralized handbook Valerie gave him followed the US EPA's asset management process closely. He started with the first step on the loop, "Analyze the existing situation." He knew more about the wastewater treatment systems he was responsible for than a lot of communities know about their systems, because The Zone made scheduled pumpouts of all septic tanks. He knew where the systems were and, in theory, what type of systems they were. The Zone had not "ground truthed" all the permit data they inherited from Sandy Bay, but they had filing cabinets full of permit data that they used regularly. In addition to the paper files, some basic system information was digitized to help The Zone automate its inspection and re-permitting process. Jerry had a record of which systems passed and failed inspections, and which passed inspection after being repaired or upgraded, and he knew when all of this happened. Still, it was hard to get an overview because so much of the information was on paper. He decided that part of the existing situation was a need to get more information digitized.

Jerry drew up a description of the existing situation with the overview information he had and used that as part of the application for the funding Valerie had talked to him about. Then, conscious of Valerie's emphasis on the need for public participation and of the central role of "stakeholder communication" in the framework he was working from, Jerry scheduled a public meeting. He decided that his goals for the public meeting were to communicate his analysis of the existing situation, to explain the process that The Zone was starting, and to listen to stakeholders. In addition to using the usual channels for announcing The Zone's public meetings, he wrote a note to Tom, the spokesperson for SBEA, saying he hoped to see him there.

Jerry was not disappointed. The meeting took place on a November evening, and November meetings were generally better attended than those held during warm, light summer evenings. Thirty people showed up, twenty-five of them from SBEA. The rest were the health officer of Sandy Bay, two Board of Health members, and Valerie and Jim. Jerry began by acknowledging the work SBEA had done to identify issues with water quality and said he looked forward to working with them all to preserve and protect their water quality. After acknowledging the concerns, he touched on the uncertainty about the sources of fecal coliforms and nutrients, but told the group that he was determined to find ways to improve the performance of The Zone's wastewater treatment without waiting for certainty. After describing the framework he was starting to use and giving his overview of the existing situation—which he hoped would build the audience's confidence that he really was starting on the framework—he opened up the floor.

In the first half hour, almost none of the comments responded to the overview or the framework. Jerry heard again and again about the people afraid to swim at the beach, the visitors who were staying away from town, and the shellfisheries. Most people expressed or implied a certainty that onsite systems were the problem, and one person described how the waters in the hypoxic area smelled like a septic tank when boaters pulled up their anchors. Jerry explained that a septic tank and a hypoxic zone both have low levels of dissolved oxygen and so produce similar smells, regardless of the source of the hypoxia, but the speaker did not seem convinced.

After the initial venting, comments turned more toward the framework Jerry had outlined. Many expressed skepticism towards what they called "just another study," but some said they saw it as a rational way to move forward—as long as extending the sewer was one of the options considered. Jerry had a hard time accepting that. Did they expect The Zone to embark on a plan to put itself out of business? Still, he realized that it would not help to dismiss the suggestion, so he tried to show interest in considering a sewer extension while making no specific commitments. Jerry ended the meeting, after the comments seemed to be over, by thanking everyone for their participation and promising to keep them posted on new developments.

(Continued on next page)

Valerie and Jim stayed after the other participants had left. As they discussed the meeting with Jerry, Valerie expressed concern about public confidence in Jerry's ability to consider sewer extension fairly. "You know," she said, "I think this process may not work with The Zone in charge. I'm thinking that we need to put the City of Sandy Beach in charge, so the process is seen to be more outcome-neutral."

Jerry objected because the city ran the sewer district, so they were vested in a technology, too. Valerie and Jim reminded Jerry of all the difficulties the city would face in expanding the sewer district, and suggested that the city probably was not eager to take that on. Jerry did not like someone else steering the process, but he saw the logic of the outcome being more trusted if The Zone was not in charge. Besides, the NRD was the potential source of money for the process. Jerry agreed to meet with Valerie together with the mayor and the health officer of Sandy Bay to see about their interest in driving the framework process. He also agreed to meet Valerie to think through the next step, setting performance standards.

(Case Study continues on page 5-2…)

5 RELIABILITY ASSESSMENT TOOLS

What does a regulatory performance standard mean? For example, if an effluent standard is set at 20 mg/L nitrate nitrogen, does that mean that the system must perform under that standard *all* the time? Half the time? Ninety nine percent of the time? The study of reliability provides language and concepts to answer these and other questions about wastewater treatment system performance. For this handbook, reliability of a wastewater treatment system is defined as "the probability of adequate performance for a specified period of time under specified conditions or...the percent of the time that effluent concentrations meet specified permit requirements" (Metcalf & Eddy 2003). In this section, the performance standards used as examples in the handbook are established, and several tools are described that can be used to determine whether systems are meeting those standards.

5.1 Performance Standards

A fundamental part of choosing reliability tools and data sources is deciding what type of reliability will be assessed. Enumerating a system's performance standards from the perspective of all stakeholders is a painstaking exercise; one system reliability expert (Moubray 1997) says "this step alone usually takes up about a third of the time." For the purpose of illustrating reliability tools in this handbook, two high-level performance standards were chosen that are indicative of (1) "quantity" failures and (2) "quality" failures:

- Adequate hydraulic dispersal of the effluent, defined by absence of effluent on the surface of the soil absorption system (SAS). This standard or a similar performance standard is found in many jurisdictions. Whether the wastewater treatment system is meeting the standard at any given time is readily observable. On the other hand, meeting the standard does not guarantee adequate treatment. Unless there are observation ports in the SAS, it takes more complex measures than repeated visits to determine whether a system is complying with the standard by a large or small amount—that is, whether effluent is or has been near the surface of the SAS.
- Nitrogen content in the effluent of $\leq$ 20 mg nitrate-N/L before the soil absorption system. There are many jurisdictions where nitrogen standards are applied; however, an arbitrary nitrogen standard was chosen for the sake of discussion. This performance standard differs in several ways from the hydraulic dispersal standard. Simple inspection is insufficient to determine whether the standard is being met at a given time: instead, sampling and laboratory tests are required. Meeting the nitrogen standard does guarantee adequate treatment, at least for nitrogen, at the time of the sampling event and upstream from the sampling point. Finally, sampling and testing once is enough to determine whether the system is meeting the standard by a large or small margin (at the time of the sampling), and a series of repeated sampling and testing gives a view of the variability in system performance over time.

Many other performance standards might be chosen; some were mentioned in Section 3.3.1. A far-from-exhaustive list of other performance standards, both quantitative and qualitative, for decentralized wastewater treatment systems or their components includes:

- Total phosphorus levels in pretreatment effluent ≤ 0.5 mg/L
- $CBOD_5$ (five-day carbonaceous biological oxygen demand) levels in pretreatment effluent ≤ 25 mg/L
- TSS (total suspended solids) levels in pretreatment effluent ≤ 25 mg/L
- FOG (fats, oils, and grease) levels in pretreatment effluent ≤ 25 mg/L
- No detectable fecal coliform organisms per 100 ml in at least 75% of the samples, with no single sample to exceed 25 fecal coliform organisms/100 ml
- Physical integrity of system components
- Life-cycle cost is less than or equal to that of a centralized system for the same area
- 75% of total phosphorus is recycled to agricultural use
- The septic tank is water-tight, both with respect to leaks in and out below the fill line and leaks in of water from above the fill line
- Effluent is distributed evenly to all trenches in the SAS
- System owner and others are exposed to little or no bad odors or unpleasant sounds

Valerie arrived at Jerry's office to discuss possible standards to use as measurements of whether the performance of The Zone's onsite systems was improving. They thought about what people had said at the public meeting—warnings about the beach waters, closings of the shellfisheries, and the hypoxia were issues many people had returned to. Clearly some sort of protection from the spread of pathogens and from eutrophication would address the issues people were most concerned about. "So how do we handle the regulator's nightmare with decentralized systems?" Valerie asked. "A lot of the treatment takes place in the soil, and it is quite expensive to set up monitoring for any given system, let alone very many or all of them. So we can come up with performance standards all we want, and state law has a number of them which apply at the property line, but how can we possibly tell whether a system is meeting them or not?"

"Any performance standard that calls for groundwater monitoring to see whether it's being met is a standard that will be ignored in practice," agreed Jerry. "What we need are standards that are easy to monitor and meaningful with respect to pathogens and nutrients."

"Right. We need proxy standards." Valerie thought a bit. "How about the old chestnut of surfacing effluent? Can we agree that a wastewater treatment system that allows untreated or partially treated effluent to surface is likely to be spreading pathogens? The path may be children or dogs playing in the effluent, or spreading to surface water through runoff from rains or even flow during dry weather."

(Continued on next page)

"Well," Jerry considered, "surfacing effluent is one way to spread pathogens. I hate to be sitting here and telling a regulator ways our systems can contribute to public health issues, but there are certainly other ways that pathogens can be spread to people than through surfacing effluent. If the groundwater is shallow, or travel time to surface water is short…"

"Sure, and that's all right," interrupted Valerie. "In a few more years, maybe we'll have cheap, reliable, quantitative techniques to determine where a given pathogen in groundwater or surface water has come from, and maybe we'll be confident that none of the onsite systems around here have surfacing effluent. For now, how about taking elimination of surfacing effluent as a performance standard for The Zone? Or is that setting the bar too low? Maybe you've already achieved that?"

Jerry shook his head. "I'd like to say yes, but I doubt it. The regulations don't require us to test for surfacing effluent. If we see it, we fix it, but we don't make any special attempts to find systems with surfacing effluent. Especially the older systems, where we just perform function checks every six or seven years. They might be experiencing surfacing in February, March, and April, but our inspection in July or August finds a dry, green lawn."

After some more discussion, they agreed to use no surfacing effluent as a performance standard and revisit other potential performance standards related to the spread of pathogens in five years or so. Jerry thought they were finished. Valerie did not.

"You know," she said, "nitrogen is a growing issue along the coast. Look at these hypoxic zones we have here. They don't come from pathogens! The EPA has been pressuring state agencies to establish nutrient standards in sensitive coastal areas, and I'm on a working group looking at that issue. It looks like nutrient standards are going to affect your work, too, so now would be a good time to start preparing for it. The way the discussion is going, in a few years, Sandy Bay will probably be required to put in place a program of onsite system standards for nitrogen."

"Boy, if you start putting nitrogen standards in place for onsite systems, that's going to cause some real costs" exclaimed Jerry. "Systems with just septic tanks and laterals don't reduce nitrogen much, so you need to add an advanced treatment component. They aren't free, and they generally need a lot more frequent maintenance than gravity-flow systems with septic tanks and laterals."

"We're aware of that," Valerie reassured him. "There's no talk of phasing in standards overnight. Eventually, we'll try to arrange funding for Sandy Bay to prepare an assessment and plan for the State, including GIS mapping and the MANAGE computer model for predicting effects of nutrient sources. Sandy Bay will be free to meet the nutrient standards any way it wants, but I expect that higher treatment standards along the beaches and shellfish beds—and perhaps some setbacks—will be part of the plan. Everything doesn't have to be done at once. Advanced treatment may be required for systems needing repairs, for home expansion permits, or when the house is sold. If the rate of system upgrades from that sort of 'natural' turnover seems to be too slow, eventually all systems in zones contributing nitrogen to the surface waters may need to be replaced on some sort of schedule. But that's years off."

"That sounds like a lot for me to think about, and I appreciate the heads up. I'm trying to wrap my head around how it affects our choice of performance standards. We know from studies that onsite systems without advanced treatment don't denitrify much. But to try to monitor the effluent as it flows away from the leachfield to verify whether this is true or not is very expensive. So we're left with maybe spending a lot of money to get an answer we already know. How has that helped us?"

(Continued on next page)

"I agree that monitoring of in-ground flow of effluent is not the way to address nitrogen performance standards. And I don't think we need to set nitrogen performance standards for existing systems right now. Once we get the results from the MANAGE model on where our zones of contribution are, then we can talk about short-term and long-term standards for systems there. In the meantime, we could take a precautionary approach to setting nitrogen performance standards for new systems—say, any new systems installed within 300 feet of surface water need to achieve 20 mg/l nitrate nitrogen or less."

"That's fine, if we can get funding to cover the extra cost, or if we can get a rate increase," said Jerry. "There are both up-front costs and ongoing costs of monitoring and maintenance to think about."

"Sure, this needs to work within your business plan," Valerie replied. "How about we put nitrogen standards aside now until the next time you ask for a rate increase, and then we incorporate it? For now, I'm more than satisfied that you're gaining experience in understanding reliability vis-à-vis surfacing effluent and can use that experience for other performance standards later."

Jerry was relieved to be off the hook for nitrogen standards, at least for now. Even with surfacing effluent standards, he was concerned about the cost implications. "Speaking of rate increases," Jerry said, "I'm sure you realize that it's going to cost money to find out where we do not achieve these performance standards, and then to achieve them everywhere. Even with help from the NRD to do the first step, rates will need to go up to achieve these standards."

"Yes," said Valerie, "of course. And when you go to ask for the rate increase, you'll have a well-documented reason for it. The choice will be clear—current levels of service at current rates, or specified higher levels of service at specified higher rates. In either case, I expect the rates will be cheaper than the sewer alternative."

(Case Study continues on Page 5-14…)

5.2 Introduction to Reliability Tools

The reliability of specific components or even entire decentralized wastewater systems is critical for environmental and human health, to ensure the lowest possible ongoing costs for operating and maintaining the system, and to stay in compliance with regulations. Reliability tools also help enhance the initial design of new systems, assist operators in troubleshooting problems, and provide community leaders and regulators with key information to diagnose likely trouble spots and/or locate new development appropriately.

The tools presented in this chapter and in Appendix A enable the user to explore each of these areas. These tools have been tested in real-life applications, and most have been applied in decentralized or centralized wastewater or water applications.

It is important to understand that the suite of tools in this handbook is a selection of what is potentially available. These tools hold great promise to the decentralized wastewater industry and represent a good foundation upon which to build a larger set of reliability tools.

5.3 Failure Curves

How many wastewater treatment systems fail in a year? Do any components "wear out" after a certain period of time and, if so, what is their useful life? What role does lack of regular maintenance of onsite systems play in failure rates? Failure curves (also known as decay curves) help answer these questions.

Failure curves illustrate the number of units (systems or components) in a population that are failing at any given time of the lifetime of that population, and thereby give the probability of failure. Once the basic attributes of the failure curves are established, then mean time before failure (MTBF) and other potentially useful metrics can easily be calculated.

Insights into both of the performance standards discussed above, the surfacing of effluent and the nitrogen removal standard, may be gained by analyzing failure curves.

Failure curves are plotted by analyzing actuarial data from past failures. The data required for each failure include, at a minimum, information on when the unit was installed, when it failed (if ever), and when it was last known to be performing adequately.

Much other information about the unit could also be important. The supplementary information helps define the cohort of units to be analyzed. For example, Hudson (1986) argues that the place and date of system construction (and therefore the regulations under which the system was designed and constructed), together with the soil type on which the system is installed, give ample predictive power for failure rates. He refers to this type of analysis, which groups systems into cohorts classified by regulatory period they were constructed in and soil type, as "simple cohort analysis." Hudson asserts that adding more variables to the definition of a cohort increases the complexity of the calculations more than it increases the predictive power of the analysis.

Technological changes since Hudson's work in 1986 may make it more attractive to use more variables in defining cohorts. Advances in hardware and software make complicated calculations simpler to perform. A greater variety of treatment systems have been used, and they may have significantly different failure curves.

There are currently no generally accepted ways to define a cohort of wastewater treatment systems for purposes of failure curve analysis. If detailed information such as system type, name of designer, name of installer, frequency of maintenance (including septic tank pumpouts), or other information is associated with the other data on each system, then it becomes possible to perform analyses to find out whether each factor has a significant effect on performance and therefore may be included in the cohort definition.

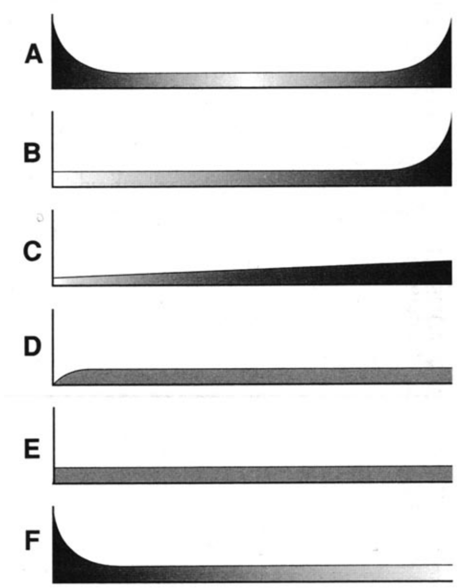
Detailed information on the mode of failure is necessary for some uses of failure curve analysis. For example, is effluent surfacing because the entire SAS is clogged or because the distribution box is tilted and only part of the SAS is being used? With information like this, more nuanced pictures of failure patterns can be drawn, more accurate life-cycle cost calculations can be made, and it becomes easier to make decisions about types of intervention that could reduce failure rates.

Without information on modes of failure, failure curve analysis still has many uses. For example, failure curves can be used to decide how often a system manager will inspect a system to see whether failure has occurred—regardless of the failure's cause.

5.3.1 Possible Shapes of Failure Curves

Examples of failure rate distributions over time for systems or system components are given in Figure 5-1. The discussion of the different curves and their implications for maintenance procedures is taken from Moubray (1997).

In all these failure curves, the X-axis is time and the Y-axis represents the conditional probability of failure. The conditional probability of failure is defined as the probability that a member of the population at the beginning of a time period (for example, a year) will fail by the end of that time period.



(Moubray 1997)

Figure 5-1
Six Patterns of Failure

- **Pattern A**, the so-called bathtub curve, shows a relatively high number of failures in the beginning of a unit's life (sometimes called the period of infant mortality), followed by a period of approximately constant failure, followed by a wear-out time. The curve shown in Pattern A is a combination of at least two failure modes—one that brings about the infant mortality (Pattern F), and one displayed at the wear-out phase (Pattern B).

- **Pattern B** applies to units that fail in relatively small numbers over a useful life, after which the failure rate rapidly increases. Establishing the useful life for a unit is done by gathering enough actuarial data to plot a curve like Pattern B. Maintenance procedures will vary, depending on cost of detecting failure, consequences of failure, and costs of overhaul or replacement. For those units with high consequences of failure, the key datum for scheduling maintenance tasks is the length of the useful life.
- **Pattern C** has a steadily increasing probability of failure, without any clear end of useful life. It can be associated with material fatigue. The slope, which can vary from nearly flat to rather steep, will have a strong influence on the maintenance strategy chosen.
- **Pattern D** is similar to Pattern C, except that there is a brief period of very low probability of failure early in the unit life.
- **Pattern E** shows a constant rate of failure over time. The distribution of failure over time suggests no critical time for maintenance interventions. In fact, in many industries, maintenance has been documented as the *cause* of many failures. Reduced maintenance of components that show pattern E may reduce failure rates.
- **Pattern F** is the beginning of the bathtub curve, without the wearout period at the end. A high infant mortality is followed by constant or gradually increasing failure probability. In the civil aircraft industry, studies have shown that more than two thirds of the units follow this failure pattern (Moubray 1997). Reactive maintenance is usually the most efficient way to address infant mortality failures. In decentralized wastewater treatment, Pattern F and Pattern A both indicate problems with siting, design, and/or construction—either standard procedures were not followed or they were inadequate.

The shape of the failure curve helps determine which further metrics can give important information. MTBF (mean time before failure) is a commonly discussed metric. This metric can give significant information about the expected useful life of a unit that exhibits failure curve patterns A or B. Consequently, the units can be targeted for intervention (such as replacement, more frequent inspections, or other measures) at the time when the populations start wearing out. For units conforming to the other patterns, which have no distinct time that they start wearing out, MTBF does not give meaningful information about when to accelerate interventions. MTBF may, however, still be useful in life-cycle costing calculations.

5.3.2 Cohort Analysis: Grouping Systems for Failure Curve Analysis

An early step in applying failure curve analysis to wastewater treatment systems is deciding which systems to analyze. Decentralized systems in many areas have a range of ages, from fifty or more years old to new construction. Typically, regulations governing system design and installation have changed a number of times over the years. Lumping all the systems together for failure curve analysis hides any differences in failure rates there might be among systems built according to different specifications.[5]

[5] The availability of data on system failure often varies historically, as well. As is discussed below, one source of data on failures is permit data—for which systems have permits for repairs been issued? Experience shows that little or no permit data exists from before 1970.

Hudson (1986) identifies a range of methods for forecasting failure rates. The simplest method, "old is unacceptable," implies a 100% failed status for systems installed before a certain date and requires replacement of all older systems. As Hudson points out, applying this method may result in effectively performing systems being replaced. At the other end of the complexity gradient is "full statistical analysis," for which he says a number of models are available. Hoover's statistical field sampling, or "scientific study" method, is one such model (see, for example, Hoover 2003). Full statistical analysis requires more data and more statistical expertise than the other forecasting methods examined. Hudson applies the Goldilocks principle (not too much and not too little, but a "just right" level of complexity that achieves maximum value without waste or insufficiency) to the range of forecasting methods. Hudson recommends "Cohort raw failure rates" as striking a balance between usefulness and complexity.

A "cohort" of wastewater treatment systems is a group of systems that shares one or more common properties. Hudson recommends using the regulations in force at the time of system construction as the primary basis for establishing cohorts. For example, if a jurisdiction underwent major changes in the decentralized wastewater code in 1972, 1985, and 1992, four cohorts of systems would be analyzed separately: pre-1972, 1972–1984, 1985–1991, and 1992–present.

Hudson also recommends using information about soils into which the systems were installed when defining cohorts. In the example above, each time-based cohort might be further divided into systems established on low-permeability, medium-permeability, or high-permeability soils, creating twelve cohorts instead of four. Cohorts could also be created using the type of system, system designer and/or installer, year installed (some years are wetter than others), time of year installed (some seasons are wetter than others), or any other criterion for which data are available and which may add to the usefulness of the analysis. Each additional criterion used in defining cohorts increases the number of cohorts and, therefore, also increases the number of data points necessary to draw statistically significant conclusions. In deciding how to define cohorts, it is important to consider the quality and amount of data available, the resources available for analysis, and what level of detail in conclusions is desired.

Calculation of raw failure rates is independent of time of failure, so Hudson's recommended method stops short of establishing failure curves. (Indeed, in the data he examined, he found the failure curves to be flat—annual failure rate remained constant over the length of the system lifetime examined. See the text box, "Applying Failure Curves," which follows.) However, the division into cohorts is also an early step in establishing the shape of failure curves, and Hudson shows how to analyze a cohort to see what the shape of the failure curve is.

5.3.3 Establishing the Shape of a Failure Curve

Hudson (1986) gives a simple way to determine the shape of the failure curve. His study is of systems with surfacing effluent, but the principles are broadly transferable. The null hypothesis (that is, the hypothesis to be disproved) is that the systems exhibit failure curve pattern E, a constant failure rate over time. In a hypothetical example, Hudson tests whether the failure rate is steeper in the first three years of system life than over the next three years, that is, whether the systems exhibit patterns A or F. The test is performed by comparing the failure rates in the two time periods and using the Student t-test to see whether the difference is statistically significant (shown in the following example).

Given a large amount of data, the data can simply be plotted with conditional probability of failure versus time. As the example shows, however, simple inspection of the data may be insufficient to determine the shape of the curve. Multiple hypotheses about which parts of the curve are steeper may need to be tested to come up with the "true" shape.

GIS tools can potentially be used to conduct more complex cohort analysis, since cohorts can more easily and accurately be defined in terms of spatial properties like depth to groundwater (see Section 5.4).

Example of Determining the Shape of the Failure Curve

Hudson (1986) gives a hypothetical example of a population of 74 onsite systems built over a six-year period. These 74 systems comprise a cohort that enables them to be fairly compared with each other. For Hudson's purposes, that means that they are built under the same code and on the same type of soil. Failure could be defined as surfacing effluent or failure to meet a nitrate standard; the definition is not important in demonstrating the calculation. The null hypothesis is that the failure rate is constant over the six years.

He constructs a table of survivors (Table 5-1):

Table 5-1
Survivors at End of Each Year of Operation (Hudson 1986)

Year Built	1975	1976	1977	1978	1979	1980	*Total*
Number built	10	8	17	22	5	12	*74*
Year 1	9	8	17	19	5	10	*68*
Year 2	8	8	15	19	5		*55*
Year 3	8	7	14	17			*46*
Year 4	8	7	13				*28*
Year 5	7	6					*13*
Year 6	7						*7*

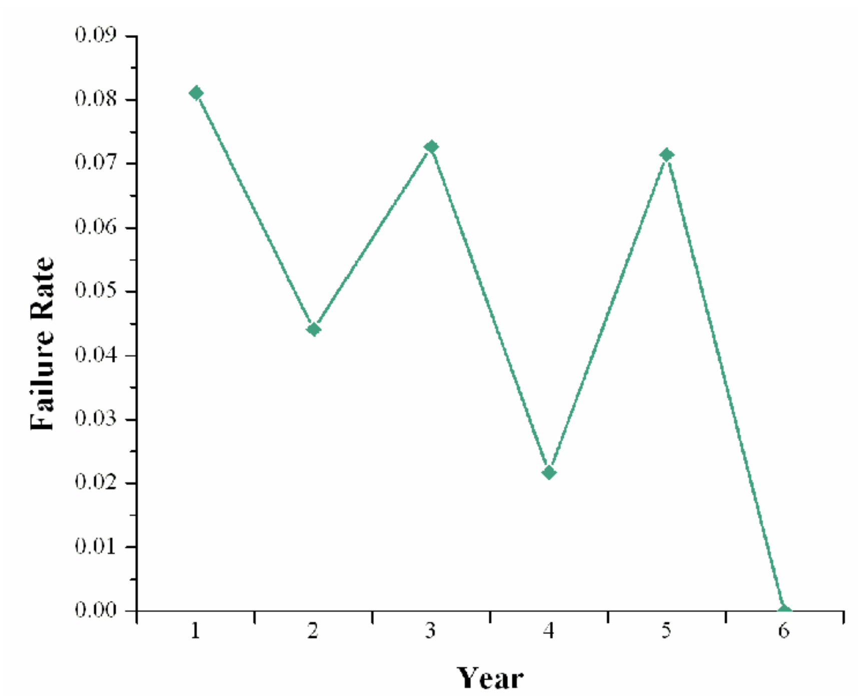
From the information in the table of survivors, he constructs a table showing the failure rate each year (Table 5-2):

Table 5-2
Failure Rate Summary Table (Hudson 1986)

Year	Systems at Start of Year	Failures	Failure Rate
1	74	6	0.0811
2	68	3	0.0441
3	55	4	0.0727
4	46	1	0.0217
5	28	2	0.0714
6	13	0	0.0000

Do the data show signs of infant mortality?

A plot of the conditional probability of failure (simply, the failure rate in each year) is shown in Figure 5-2.



(Hudson 1986)

Figure 5-2
Conditional Probability of Failure vs. Time

The plot is not as clear-cut as the archetypical shapes A–F presented in Figure 5-1. The 74 systems and 6 years represented in this population are too small of a population and/or too short of a time span to allow determination of the shape of the failure curve by inspection.

To answer the question for data over this short time span, Hudson asks whether the average failure rate is greater during the first three years than during the last three years.

The failure rate during the first three years is the number of failures during that period divided by the number of system-years:

$$\frac{6+3+4}{74+68+55} = 0.066 = 6.6\%$$

Similarly, the failure rate during years 4 through 6 is

$$\frac{1+2+0}{46+28+13} = 0.034 = 3.4\%$$

The failure rate of 6.6% is higher than the failure rate of 3.4%. On this small sample, is the difference statistically significant?

The question is answered by applying a statistical test of difference in proportions, assuming a single underlying population. The formula is

$$z = \frac{(P_1 - P_2)}{\left[(pq)^{1/2} x\right]}$$

where z = the value of a standard normal distribution calculated using the underlying population (for more detail, see Neter and Wasserman 1974)

P_1 = failure rate, years 1–3

P_2 = failure rate, years 4–6

Y_1 = total system-years, years 1–3

Y_2 = total system-years, years 4–6

$p = \frac{(Y_1 P_1 + Y_2 P_2)}{(Y_1 + Y_2)}$, the overall failure rate

q = 1 – p

$$x = \left[\frac{(Y_1 + Y_2)}{Y_1 Y_2}\right]^{1/2}$$

With $P_1 = 0.066$ and $P_2 = 0.034$, then p = 0.056, q = 0.944, x = 0.129, and the value of z = 1.0615. This value is compared against the Student t-distribution as shown in tables found in any statistics text (for example, Moore and McCabe 2003; Triola 1992).

Degrees of freedom (df) are calculated by

$df = N_1 + N_2 - 2 = 197 + 87 - 2 = 282$

where N_1 = the number of system-years used to calculate failure rates in years 1–3
N_2 = the number of system-years used to calculate failure rates in years 4–6

At the 0.05 confidence level, a value for z of 1.96 or higher is necessary to achieve statistical significance (Table 5-3). The difference is not, then, statistically significant.

Table 5-3
T-Distribution: Values z Must Exceed to Demonstrate Statistical Significance at the 0.05 Confidence Level

df\prob	0.05
1	12.7062
2	4.30265
3	3.18245
4	2.77645
5	2.57058
6	2.44691
7	2.36462
8	2.306
9	2.26216
10	2.22814
15	2.13145
20	2.08596
25	2.05954
30	2.04227
∞	1.95996

Even a failure rate apparently twice as high during one interval as during another is not statistically significant with this small amount of data. This lack of statistical significance shows the importance of including large numbers of system-years in the study to ensure a sufficient sample size for statistical tests. If both the number of systems built and the number of failures each year are multiplied by 10, for example, then the value of z = 3.36 and the differences are statistically significant at the 0.05 confidence level.

Applying Failure Curves

Hudson (1986) analyzed failure rates for cohorts he defined using data in four previous studies. He performed linear regression analysis using the formula

Failure rate = $b_1 + b_2(\text{Age}) + b_3(\text{Early})$

where

Age = age of systems in years

Early =1 for ages 1–5 (shorter periods were tested and the results were similar)

0 otherwise

b_n = coefficients estimated from the data

The only age effect Hudson found "approaching" statistical significance was negative, that is, systems failed less often as they aged. In one cohort on stratified sand and gravel, he found signs of infant mortality (Early), but the failure rates were still low. The overall failure rates for the 36 cohorts range from 0 to 3.1% failures each year. The younger cohorts, built under stricter regulations, tended to have lower failure rates.

In a forthcoming study conducted in Wake County, North Carolina, North Carolina State University soil scientist Michael Hoover and his colleagues also found relatively flat failure curves. Strictly speaking, they used correlation analysis rather than failure curves, and they found that age explained only 15% of the observed failures (Hoover, personal communication).

5.3.4 Cohort Analysis and Failure Curves Applied, Step by Step

The following steps can be used in applying cohort analysis and, if desired, failure curves:

1. Determine what questions the analysis is to answer and which systems are of interest.

2. Determine what data are available on the systems: Health Department permits? Inspection reports? Soil type from permits and/or inspections and/or soil maps? Digitize the data into a spreadsheet, or preferably a database, if it is not already digitized.

3. Based on the questions to be answered and the quality and amount of data available, define possible cohorts. One may wish to start by analyzing cohorts defined by regulatory phase and then subdivide those cohorts later if it seems useful to do so.

4. For each cohort, calculate the raw failure rate, that is, divide the number of failures reported by the number of systems constructed. If the raw failure rate for a cohort is very low, then one may wish to stop the analysis for that cohort. Subdividing the cohort into different categories or constructing a failure curve would yield little additional information.

5. If construction of a failure curve is desired, group the systems into a table showing the survivors to the end of each year of operation (see Table 5-1) and a failure rate summary table (see Table 5-2).

6. Make a figure showing conditional probability of failure versus time (see Figure 5-2).

7. Examine the figure and develop hypotheses about the possible shape of the failure curve, for example, "Failure in years 5–15 is higher than in years 1–5." Test those hypotheses using the method described in the previous section.

8. If it seems useful, add another criterion (for example, soil type) to the cohort definition and return to step 4.

Review the questions that the analysis is to answer and the results to see whether more data would be helpful to improve the results. If so, plan how to gather the data needed to refine the analysis. If jurisdiction over the systems is available, it may be desirable to look for ways to gather the data while improving the overall performance of the decentralized systems. For example, in Massachusetts, inspection of the onsite system is required when a property is sold or otherwise transferred. If the system does not pass the inspection, the law requires repair, upgrade, or replacement within two years. Time-of-transfer inspections accumulate additional data at whatever rate property ownership turns over; if more data is desired more rapidly, then some other trigger for inspection would be more appropriate.

Even as Jerry was working on assessing and improving the performance of the existing systems, The Zone was being called upon to consider expanding its service. Scott, the real estate developer who owned one of the sets of unbuilt subdivisions outside of Sandy Bay, paid a visit to Jerry. He brought a map of the proposed housing on the subdivisions.

"Here's what we have planned," Scott said, as he unrolled the map on Jerry's desk. "There are a hundred and twenty houses planned here, and we need a way to handle their wastewater. In the past, I've just put in septic tanks and turned the operation over to the homeowners. They buy a sewage treatment plant along with the house. Keeping the sewage treatment plant working is their responsibility, just like it is to repaint the house when it needs it and keep the lawn mowed. Trouble is, this new bill passed last year by the legislature changes everything. As I'm sure you know, with a subdivision of over 50 house, now I'm required to ensure that there is a utility that will own the sewage systems and manage them properly. The law also says that I'm required to inform the home buyers of the fees that this utility will charge them. So how do I do that? I'm a home builder, not a sewage treatment expert."

"You're looking for someone to take on the role of the utility?" asked Jerry. Scott nodded. "Well, that's close to what we do now. Technically, we're not a utility. That is, we're not regulated under the state's Public Utilities Commission. We are chartered by the city, and operate under their authority. We don't own the systems we're responsible for, just maintain them. Still, there are a lot of similarities. I'm sure we can put together a proposal that would work for both of us."

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Jerry and Scott pored over the map together, discussing the site and soil conditions. Most lots were 2 acres apiece, though there was a cluster of 20 houses on 5 acres, with 35 acres of open land next to them. The soil varied quite a bit. In some places it was well drained and deep; there did not seem to be any obstacles to putting conventional treatment systems on those lots. Down in the river bottomlands the soil was heavier and groundwater was nearer the surface. The 20-house cluster was on a more challenging site near the river; Jerry thought he would probably put in recirculating sand filters or some other treatment unit there to get a cleaner effluent, so he could put in smaller soil absorption systems. Either that, or put in a cluster system, with the SAS somewhere on the 35 acres of open land.

Jerry called a friend of his who worked at the electric company to find out what it was like to be a utility subject to the state's Public Utility Commission (PUC). He learned that there were a lot more requirements on the electric company than the City of Sandy Beach imposed on his operations as a responsible management entity. In particular, rate changes were quite difficult to get through, he was told. He was advised to set rates that gave him a comfortable operating margin for 15 years or more, to avoid going through the rate change process.

Jerry realized that he needed to know more about the total costs of ownership of treatment systems than he did. In Sandy Bay, he had taken over management of systems of varying ages and quality of construction that had been managed or neglected in different ways. Before The Zone was created, Jerry's previous company had built many of the newer ones and had maintained some of the systems of all ages. Still, there were a lot of unknowns in the start-up of The Zone as a responsible management entity, and so he had been given a fair amount of leeway in adjusting his rates to cover what the actual costs were. In fact, he was expected to come before the Sandy Bay City Council every year to make a financial report, and they were open to adjustments in the rates.

With a need to set rates that would hold for 15 years or more, Jerry sat down to understand the costs of owning the wastewater treatment systems. To simplify calculations, he decided to propose that Scott finance the building of all the systems and sell them to him for a dollar apiece when the houses were sold. That way Jerry did not have the extra worries of finding and financing loans to cover the cost of the systems, and the long-term cost to the homeowner would be about the same.

Once the system was in the ground and being operated, how much did it cost to operate it? And how much control did Jerry have over those costs? He could make sure the septic tank was pumped regularly and that the plumbing was in order, but if the homeowner was using twice as much water as the system was designed for, the soil absorption system would probably clog earlier than otherwise.

Jerry had read enough in the handbook Valerie had given him to know that the first step in getting meaningful cost estimates of operating various systems was to understand the useful life of the systems and their components. He decided to simplify his calculations by using just two types of systems, a conventional onsite system with a septic tank and trenches, and a system with a recirculating sand filter. Since new regulations governing the construction of onsite systems had gone into effect in 1995, he decided to concentrate his research on how the ones built since then had performed. He figured The Zone managed around 600 conventional onsite systems built in 1995 or later, and an additional 100 or so systems of the same age with recirculating sand filters.

Jerry's maintenance records only went back to 2000, when The Zone was organized. About half the 700 systems he wanted to analyze had been inspected since then. Before 2000, the City Health Department had information on major repairs done to the systems, in their permit files. Jerry decided that this was a good time to start digitizing data. In his proposal to Scott, he included a post for digitizing data on the 700 or so systems and analyzing their maintenance history.

(Continued on next page)

After some negotiation, Jerry and Scott agreed on a fee for a feasibility study of wastewater treatment, which would include rough design, capital cost, and fees for the systems.

Jerry hired a consulting firm, Applied Information Management (AIM), to digitize the information for the conventional and sand filter systems he had chosen to analyze. AIM had designed a database for municipalities to use in managing decentralized wastewater systems, and they had experience in digitizing paper data. The database also had been used for GIS analyses of wastewater treatment needs, so Jerry figured he could use the same database for both his analysis for Scott and the assessment of existing systems.

When the information was digitized and Jerry was trained in using the database, he pulled out the conventional systems that were on well-drained soils. There were 540 of those built since 1995, with the distribution shown in Table 5-4.

Table 5-4
Conventional Systems Built on Well-Drained Soils, 1995–2004

Year Built	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total
# of Systems	63	53	56	66	47	57	47	42	48	61	540

Jerry thought about how to apply simple cohort analysis. What definition of failure was he going to use? Would the definition of failure be something that would show up in the permit data and his records? In the end, he decided not to get hung up on the definition of failure. At least for his first analysis, he wanted to know what it cost to operate and maintain the systems. So he looked at the costs for all the O&M calls to the systems. Since his company had not had a monopoly on O&M before 2000, he did not have invoice records for all systems from 1995 to 2000. Partially through looking at permit data and partially through extrapolating from the systems that his company had maintained before 2000, he estimated the costs for each system in the years 1995–2000. The products of this analysis were Table 5-5 and Figure 5-3. The costs do not include the inspections on 10-year intervals that were instituted when The Zone took over management; Jerry knew he could calculate the average annual cost per system of those by dividing his $350 fee by 10.

The sudden jump in costs from 1998 to 1999 surprised Jerry for a moment, until he realized that it was an artifact of a four-year cycle of pumpouts that began in 1999 on systems constructed in 1995. To get a better picture of costs after all systems had received their first pumpout, he removed the pumpout costs, and produced Figure 5-4.

It looked like there was a jump in the annual O&M cost per system in 2000, the year The Zone had taken over maintenance of these systems. Before trying to figure out what caused the jump, Jerry asked himself whether it was real or just within the realm of random variation.

The average annual O&M cost per system over the period 1995–1999 is $6.94, calculated from the version of Table Y that Jerry produced once he had removed pumpout costs (not shown). For 2000–2004, the figure is $10.27. Was this a statistically significant difference? Jerry tried applying the test of difference in proportions used in the failure rate example in his handbook (Section 5.2.2), but found the calculations did not make sense. Trying to apply the formula below, Jerry calculated that pq = −77.47, and he knew that the square root of a negative number is not a real number.

$$z = \frac{(P_1 - P_2)}{\left[(pq)^{1/2} x\right]}$$

(Continued on next page)

Table 5-5
Cost Per System of All O&M For Conventional Onsite Systems, 1995–2004

Year Built	# of Systems	Year Operations and Maintenance Expense Incurred									
		1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
1995	63	565	524	512	260	19363	525	669	673	19614	723
1996	53	N/A	207	394	373	332	16468	625	628	462	16460
1997	56	N/A	N/A	326	205	411	512	17449	665	569	705
1998	66	N/A	N/A	N/A	442	497	781	549	20331	561	554
1999	47	N/A	N/A	N/A	N/A	254	517	476	336	14540	426
2000	57	N/A	N/A	N/A	N/A	N/A	698	412	686	493	17687
2001	47	N/A	N/A	N/A	N/A	N/A	N/A	436	503	527	526
2002	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	501	403	493
2003	48	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	540	454
2004	61	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	742
Total	*540*	*565*	*731*	*1232*	*1280*	*20857*	*19501*	*20616*	*24323*	*37709*	*38770*
Cost per system		9	6	7	5	73	57	53	56	79	72

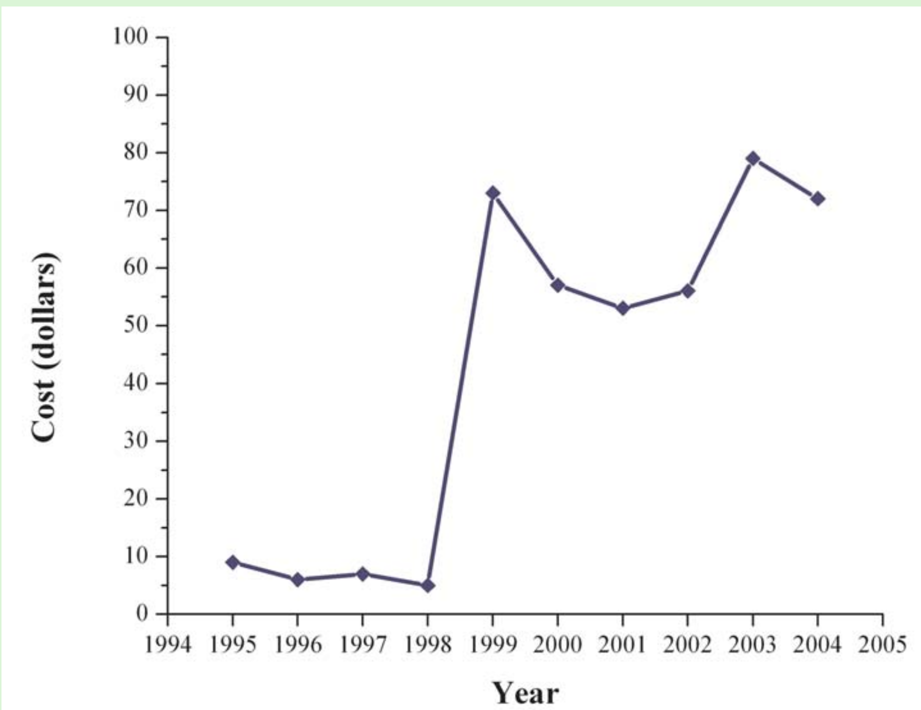


Figure 5-3
Cost per System of All O&M for Conventional Onsite Systems, 1995–2004

(Continued on next page)

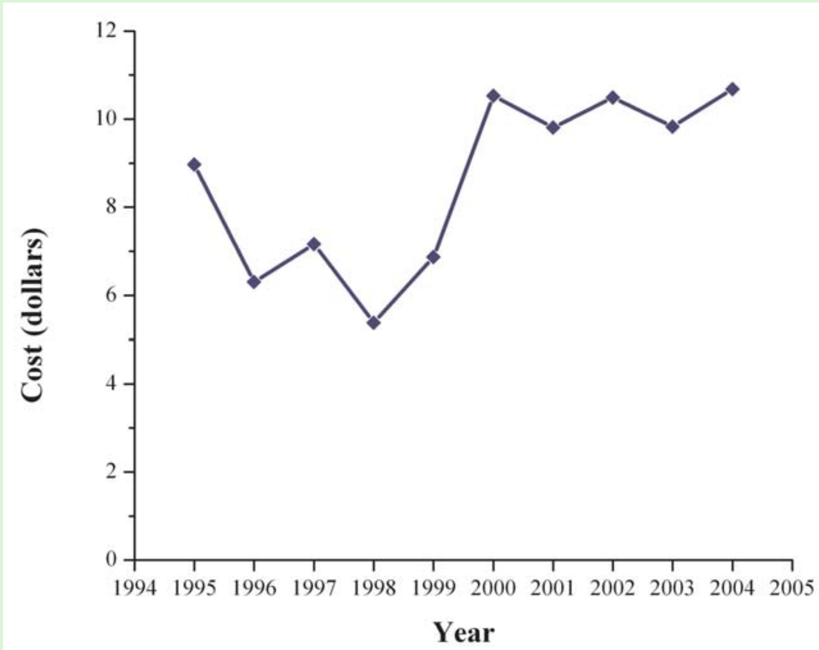


Figure 5-4
Cost per System of all O&M (Excluding Pumpouts) for Conventional Onsite Systems, 1995–2004

So Jerry called a statistician friend of his, Tammy, and explained what he was trying to do. She explained that the test of difference in proportions only works on proportions, like failure rates. “Email me over the data and I’ll show you how to apply the *t*-test.” Tammy called back after looking at the data and said, “You don’t even need to apply a test of statistical significance here. The ranges of numbers don’t overlap at all. In 1995 to 1999, the annual O&M cost per system ranged from $5.38 to $8.97. In 2000 to 2004, the cost ranged from $9.81 to $10.69. By inspection, you can say that the two sets of numbers have different means.”

Jerry was pleased to find that you could do statistics by inspection. He was less pleased with the conclusion: the jump in costs in 2000 was real. Was the jump the result of systems requiring more maintenance after they reach a certain age? The analysis thus far looked at the average cost of O&M for all systems in a year. Jerry re-analyzed the table of costs to come up with annual O&M costs per system, broken down by the year that the system was built. It made no difference whether the system was built in 1995 or 1999, there was still a statistically significant jump at the year 2000, and in each case the jump was from about $7.00 to about $10.00. Was The Zone nearly 50% more expensive—a confirmation of some people’s fears of what might happen when one organization was given a monopoly?

At this point, Jerry could not rule out the monopoly hypothesis, but he remembered the 10-year cycle of inspections, which The Zone had started in 2000. The cost of any needed repair work that the inspections revealed reflected a real cost increase in O&M. The calculations did not show the many system-years of problems that were fixed earlier because of the inspection program, Jerry reflected, or the savings from fixing problems earlier rather than waiting until they get much bigger.

Since he was just looking to get a number that would reflect the annual O&M cost per system under The Zone's management, he took $10.27 as a reasonable approximation, and added 15%. He thought that the apparently flat "failure curve"(using the surrogate of maintenance costs) that he had constructed might trend upward later in system life. After all, the oldest systems in his dataset were 10 years old, and he wanted a rate structure that would work for 15 years.

Using his work with conventional systems as the template, Jerry did the analogous calculations for systems with recirculating sand filters. In this case, there were pumps and control panels to wear out, plus clogging in the sand filter to consider. The first calculations used exactly the same method as he had for conventional systems. Then Jerry checked how it would affect the result if he tried to extrapolate on the historical data by including expected wear-out times for the electrical components. He decided that clogging sand filters would generally be avoided with the work they did during their twice yearly O&M visits on them, so he just plugged in some frequencies for replacing pumps and control panels. He estimated the frequencies from his own experience, and called the manufacturers to get their numbers. The numbers were not far off. Jerry found that the extrapolated data gave him an annual cost that was somewhat higher than he had found from historical data—with about ten systems installed per year for ten years, the data did not cover a long enough time to reflect the wearing out of electrical components.

With these calculations, Jerry had a reasonable feel for the annual costs of owning and maintaining the new systems. He needed to consider inflation, and consider whether there were any regulatory changes coming that would change the numbers, but he was most of the way there. Before turning to the capital costs of the new systems, he got back to work on The Zone's existing systems. He needed to work with Valerie and the city to set up the program he had proposed to the citizenry.

(Case Study continues on Page 5-28…)

5.4 GIS as a Tool for System Reliability Assessment[6]

A Geographic Information System (GIS) is a way of connecting various sets of information (data) to the real world. The system can be used to manage data (geodatabase), analyze data (geoprocessing), and create maps (geovisualization). A database is a system for storing specific information organized for a particular purpose. Data may be collected and stored in tables organized with a connecting field, such as a parcel identification number. The databases can include tables that store information about a topic such as owner information, wastewater system permit information, and water quality information.

A geodatabase contains the datasets representing information in terms of *features*, *rasters*, *topologies*, and *networks*.

- Parcels (lots) and soil types are examples of *features* and are displayed as polygons. Other features include streets, which are displayed as lines, and wells, shown as points.
- *Raster* (or bitmap) datasets are digital images such as digital elevation models (topography) and orthophotography[7] that can be related to the other datasets.

[6] The introduction to this section is drawn from the authors' work with GIS and from ESRI (2004).

- Spatial relationships such as *topologies* and *networks* enable the user to manage boundaries between features. *Topologies* are rules governing relationships between objects, for example, property lines do not cross. *Networks* describe objects that can be connected, which enables calculation of the longest or shortest routes possible along roads, through pipelines, and for hydrologic flow.

The user can arrange GIS datasets in thematic layers, with the most important features (for example, wastewater treatment system components) in the upper, or foreground, layer, while background information like orthophotography or topography contour lines can still be seen. The geoprocessing aspect of GIS enables the user to run analyses that show new relationships between features. Models of how to organize and use different datasets can be constructed, analysis can be run, and the outcomes can be shown on a map, tables, or other formats.

The map-making features of GIS, or geovisualization, enable the user to show previously existing datasets or results of geoprocessing on maps. Multiple layers of data can be displayed on one or a series of maps. GIS can also include interactive maps that a viewer untrained in GIS can use to turn on and off various features and layers; pan and zoom; or show 3D scenes, summary charts and tables, time-based views, or schematics of network relationships. The user can also point to an object and call up tables with additional information on that object.

Over the past few years, many upgrades in the GIS software have improved the quality of the datasets and the availability of information, as analog-to-digital conversion of existing maps on paper has become easier and searches for data have become more powerful.

5.4.1 Using GIS to Assess System Reliability

GIS currently has a number of applications in decentralized wastewater management that are related to reliability. It is being used as an environmental assessment tool, to apply hypotheses about reliability, and to identify areas where there are cumulative impacts or “hotspots.” GIS could also be used to perform types of cohort analysis that would otherwise not be feasible.

GIS has been used in numerous projects to apply rough hypotheses about system reliability and assess their implications. In Holliston, Massachusetts, for example, it was hypothesized that on parcels with too little room for an onsite wastewater treatment system, after all setback regulations were met, the wastewater treatment system did not comply with current code, and it would be difficult to upgrade the system to achieve compliance. It was also hypothesized that older (pre-1974) systems and those with shallow (less than three feet) groundwater could not achieve a compliant system without a mound—which some residents may object to on aesthetic grounds. Using these hypotheses, areas of town with the greatest need for replacement or upgrade of the onsite systems were identified, so that new management or capital projects could be prioritized for those areas. The same process could be used to identify systems for a more detailed, field-based assessment of their reliability.

[7] Orthophotography corrects distortions from the camera lens and other factors in aerial photographs to give the photographs the spatial relationships of a map. Orthophotographs are suitable for accurately overlaying other layers of a GIS-generated map.

In Rhode Island, the MANAGE model uses GIS to calculate nutrient loading from nonpoint sources, including onsite wastewater treatment systems. Such a model, combined with an understanding of process reliability (Section 5.6), could be used to set appropriate performance standards for nutrient removal in onsite systems. For example, the effect on nutrient loading from onsite systems in a new development could be calculated for nitrate-nitrogen concentration in effluent to leachfields of 20, 30, and 40 mg/L, achieved 90, 95, or 99% of the time, and that information could be used to set the regulatory requirements. (MANAGE uses units of pounds of nitrogen per acre annually. To translate achievement of different levels of reliability into units compatible with the model, data on nitrogen removal performance could be transformed into average annual effluent values.)

GIS can also be used to calculate failure curves for cohorts of onsite systems. As described in Section 5.3.3, Hudson (1986) suggests that a set of systems built during the period a specific set of regulations were applied and on similar soil types describes a cohort with high predictive power for failure rate calculation. GIS can be used to facilitate this analysis. Data on developed parcels and system or building age can typically be found in local tax assessor and permit offices. The parcel boundaries may be digitized from paper files. The data can then be grouped by regulatory period during which the systems were built. Soil polygons and soil attributes are available nationwide from the Natural Resources Conservation Service (NRCS) and are called Soil Survey Geographic (SSURGO) data. Soil types with similar drainage characteristics can be grouped to reduce the number of cohorts and thereby simplify analysis.

Seattle Public Utilities Uses GIS in Prioritizing Inspections

Seattle Public Utilities (SPU) used GIS to conduct the risk-cost prioritization of sewer pipes to inspect using closed-circuit TV (see Section 7.5). The GIS model extracted attributes on each pipe (age, material type, size), along with proximity to geologic and physical features such as landslide prone areas and places with potential exposure to hydrogen sulfide gas (for example, at the bottom of steep slopes or force main outlets). Beyond its use during the analysis, GIS could be used to prepare inspection schedules, track results of inspections, and to develop construction plans, including traffic safety setups. In Figure 5-5, the risk-cost of failure of the pipes shown in red exceeds the net present value (NPV) of CCTV inspection, so SPU plans to replace them proactively.

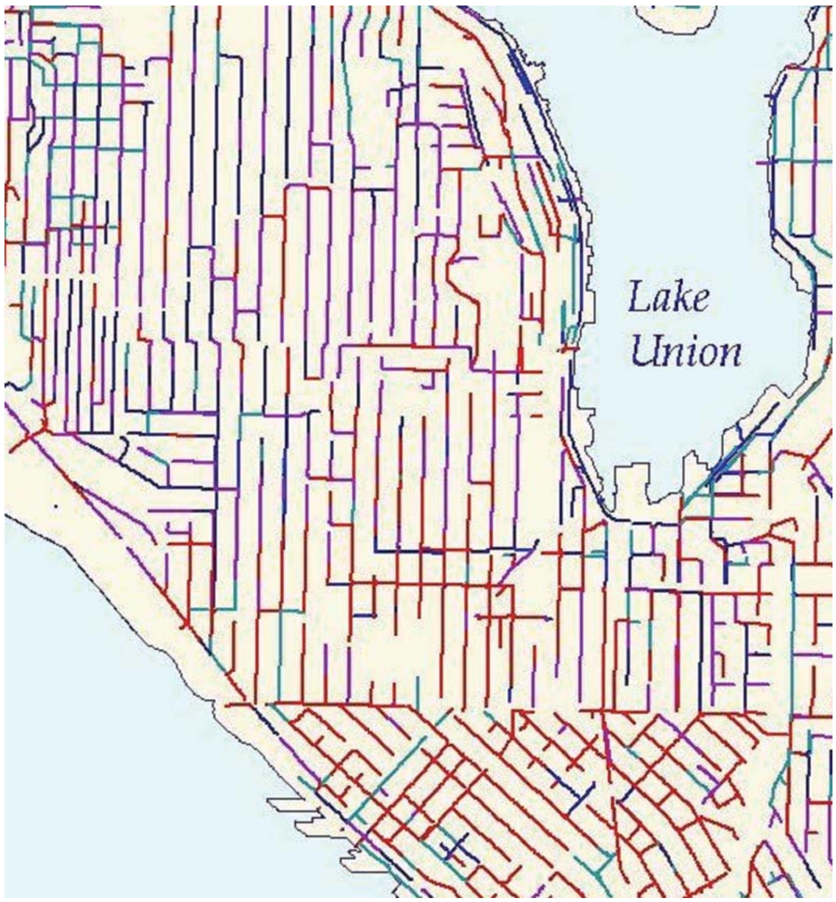
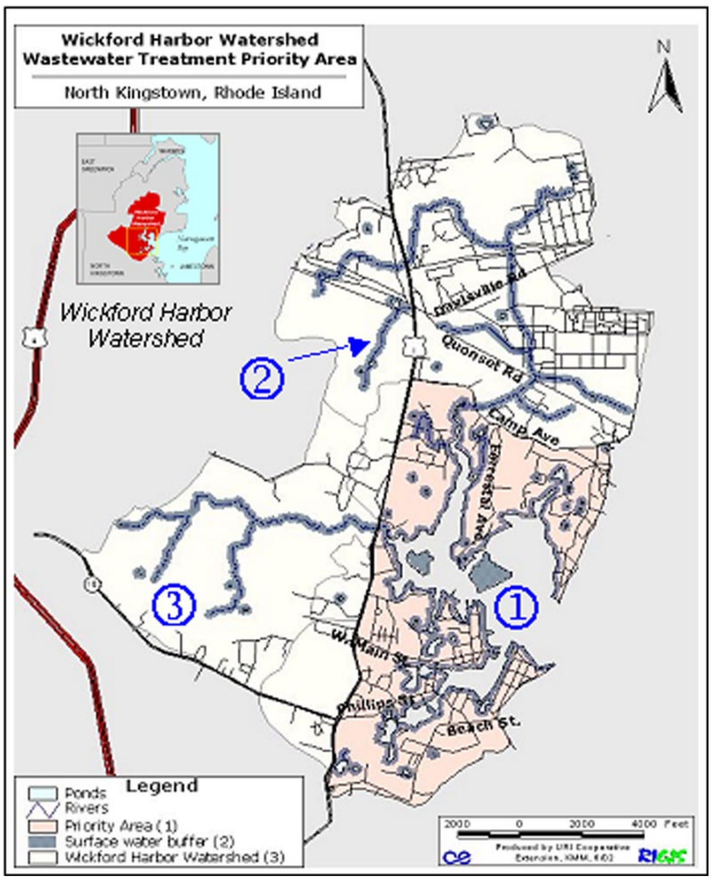


Figure 5-5
The Risk-Cost of Failure of the Pipes Shown in Red Exceeds the Net Present Value (NPV) of CCTV Inspection

Cumulative Impacts Assessment—Rhode Island's MANAGE Model

MANAGE is the name of a GIS model that calculates nutrient loading, which is used as an indicator of risk of pollution (Joubert *et al.* 2004). The model was developed for use by Rhode Island communities, and it can be modified to apply to other parts of the country. The calculations include nitrogen loading for groundwater, and nitrogen and phosphorus loading for surface waters. Nutrient loading to groundwater is calculated by summing the contributions from all potential nonpoint nitrogen sources, such as onsite systems, fertilizers, pet waste, and storm water. The model accounts for spatial relationships that modify the nutrient loading based on the land use and soils characteristics. An estimate of contributions from malfunctioning onsite systems can also be made with MANAGE. For this calculation, systems on lots with a shallow restricting layer or ones very close to surface waters are hypothesized to be malfunctioning.

A program to provide grants to cover part of the costs of repairs for advanced treatment systems was developed for Wickford Harbor, Rhode Island. GIS was used to identify applicants in critical harbor areas, along shoreline tributaries, and in locations with problem soils. Applicants in these critical areas were then given priority for the grants (Figure 5-6).



(Joubert *et al.* 2004)

Figure 5-6
A GIS Map Showing Priority Areas for Onsite Wastewater Treatment System Repair Grants

GIS can be used to sort systems into cohorts, run the analysis of failure curves for each cohort, and present the results on tables and on maps. The failure curve of each cohort may then be used to predict future failure rates. The hypothesis that different cohorts have different failure rates/curves can also be evaluated. The locations of past failures may also suggest other hypotheses about predictors for failure rates. The results of this exercise could include a map, showing location of cohorts and the failed systems within each cohort, and failure rate data that can be used to develop an estimate of system replacement costs over time. The simple cohort analysis described by Hudson (1986) is performed without GIS. (GIS was used much less commonly in 1986 than today.) Using GIS to perform the analysis makes it much easier to use spatial characteristics in identifying cohorts. For example, field data on soil type and depth to groundwater are often not available for every parcel. GIS makes it feasible to assign soil type and depth to groundwater to parcels that have no field data, using NRCS data. NRCS mapping units are drawn at a large scale, relative to parcel size in many residential areas, and they often do not correspond to field data recorded on wastewater permits. Where some but not all parcels have field data on soil type and depth to groundwater, GIS can be used with NRCS data to achieve higher precision than would be possible with NRCS data alone. For these reasons, GIS makes it feasible to improve on the spreadsheet-based cohort analysis Hudson describes.

GIS can also be used to define cohorts using spatial features that are difficult to include any other way. The example below describes how GIS was used in Holliston, Massachusetts to find area-limited parcels, that is, parcels that were apparently too small to meet current setback requirements for onsite systems. Without GIS, identifying these parcels would have been much more time consuming and, probably, prohibitively expensive. For the two performance standards used as examples in this handbook (no surfacing of effluent and nitrate-N less than 20 mg/L before dispersal), the predictive power of cohort analysis is unlikely to be increased if cohort definition includes whether or not the parcel is area limited. However, for other performance standards, for example, water quality parameters measured at property boundaries, then area-limited parcels may, indeed, have a different failure rate than their larger counterparts.

Needs Assessment in Holliston, Massachusetts

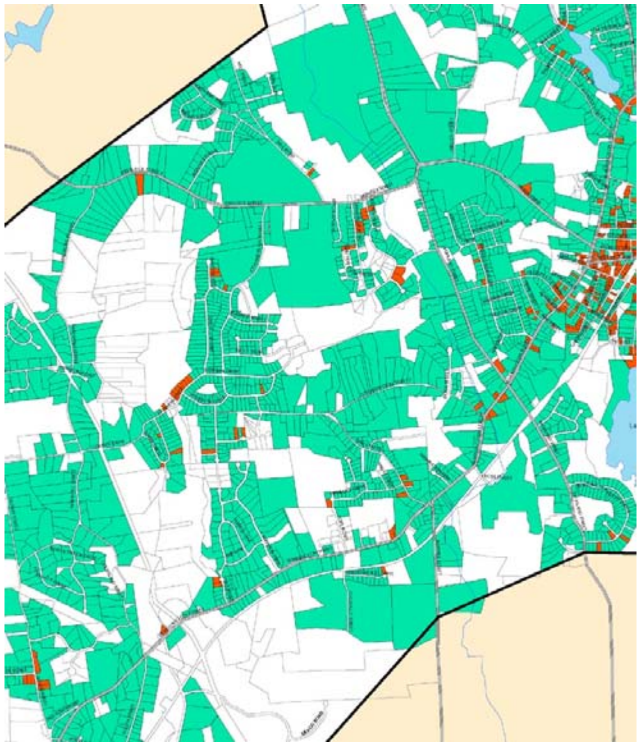
The town of Holliston, Massachusetts is a typical suburban New England community dependent solely on individual onsite septic systems. A lot-by-lot needs assessment was conducted using planning-level and parcel-specific GIS data to identify individual lots and neighborhoods that may require alternatives to onsite systems, such as cluster systems (Stone Environmental 2002). Combining planning-level data (like NRCS soil mapping data) with parcel-specific data is an approach that maximizes the information mined from parcel-specific data already available to provide a very good view of wastewater system conditions. This approach does not provide quite as good information on each parcel as could be achieved with additional field studies, but it comes close to that level of accuracy and precision without the expense of additional data gathering.

The first step in determining parcel suitability for an onsite system was to develop a map with roads, parcels, building footprints, wells and surface waters (rivers, lakes, wetlands). Buffers were added to the surface waters, wetlands, and buildings based on the minimum separation between a leachfield and the resource listed in the rules. These buffered areas are unavailable for onsite system development.

The second step was to use the data on design flows or number of bedrooms and soil conditions to determine the area needed for an onsite system. The GIS database was then used to identify the lots whose area appeared to be too small to accommodate an onsite system meeting all current regulatory setbacks (Figure 5-7).

The next step began by finding parcels with older (pre-1974) systems, which were presumed not to be compliant with current regulations (Figure 5-8). Parcels with shallow groundwater were also found (Figure 5-9); parcel-specific soils data were used where available, with the NRCS county-level soils data used on the remainder of the parcels and adjusted to improve accuracy when nearby field data were available. Because mound systems were assumed to be least favored by property owners where they are more obvious, in flat topography, parcels with low (less than 9%) average slopes were also identified (Figure 5-10). Finally, these three layers were overlaid to produce a map of parcels with older systems, shallow groundwater, and flatter topography: areas where existing systems are likely to be non-compliant with regulations and where a compliant (mound) onsite system is likely to be opposed by the property owner (Figure 5-11). While the first three criteria produced different scatterings of parcels, most of the parcels in Figure 5-11 were clustered in a few places, showing that an offsite solution might be more feasible to build for them collectively.

The area-limited parcels and those meeting all three of the other criteria were combined into a single map, showing places in Holliston where compliance with current regulations was difficult. The results of the GIS-based analysis were employed to prioritize neighborhoods with the greatest wastewater needs. The GIS maps and presentations made the scientific data easy to understand for the local advisory committee and public meetings. The town’s website presented the results of the analysis and the GIS maps were made available to all citizens in an interactive setting.



Parcels that were not suitable for onsite systems are shown in red.

Figure 5-7
Results of Available Area Analysis, Holliston, Massachusetts.

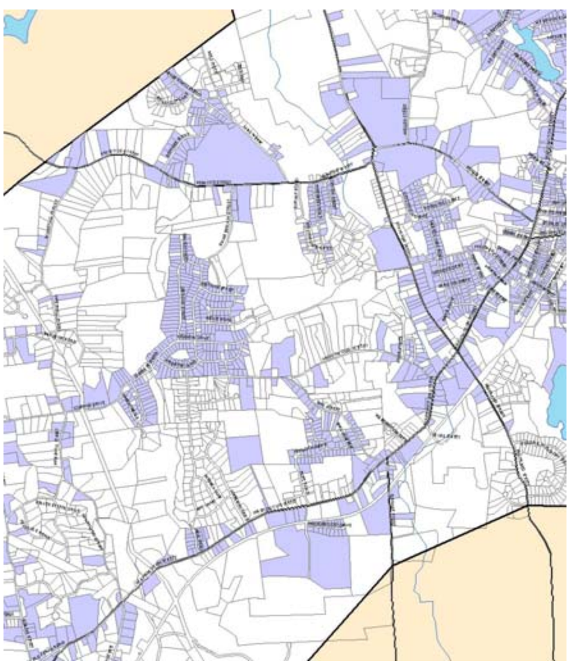


Figure 5-8
Properties With Older Systems

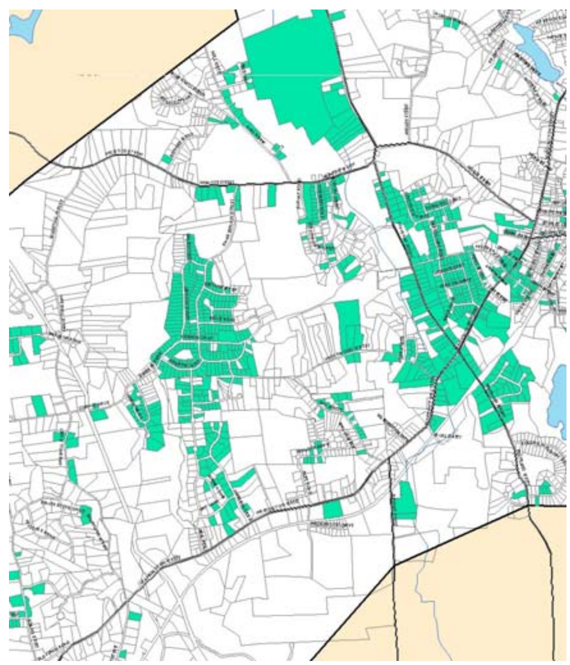


Figure 5-9
Properties With High Groundwater

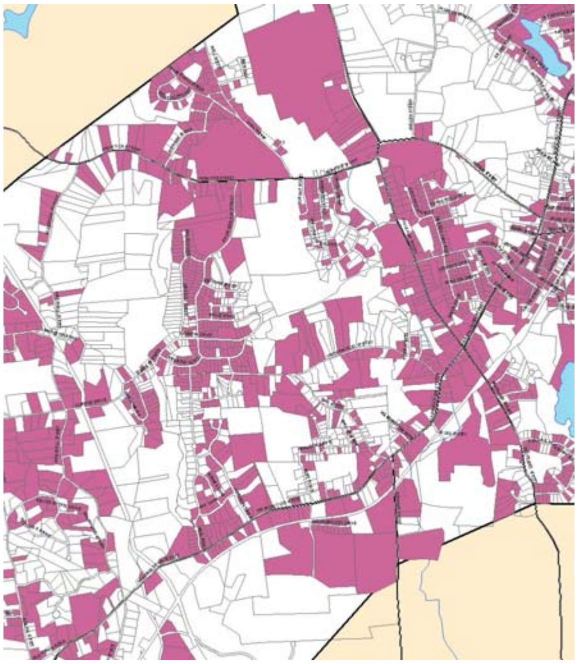


Figure 5-10
Properties With Low Average Slopes

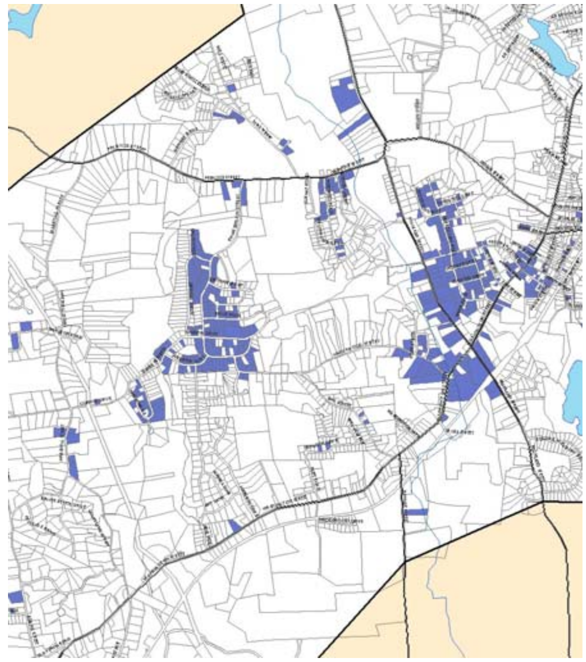


Figure 5-11
Combination of Older Systems, High Groundwater, and Low Slope

Valerie and Jerry met with Andrea and Ray, the mayor and health officer for Sandy Bay, to explain their thinking and why they wanted Sandy Bay to be in charge of the program for improved onsite system performance that they were putting together. Andrea and Ray quickly understood the importance of the program and agreed it would be good for the city to coordinate. They wanted to run it by the city council and board of health at their next meetings. Before those meetings, they agreed to take the draft application for funding that Jerry had written and write in City of Sandy Beach instead of The Zone, and otherwise modify it as they thought appropriate.

When the funding came through, Jerry realized that, even though some performance standards were designated, he was not yet ready to go the next step in the framework, designing responses. He needed to come up with a better definition of the existing situation.

The database software that AIM used included GIS (geographic information system) capabilities, so Jerry could get an overview of where the oldest wastewater treatment systems were, where the ones closest to waters were, and other specific information. He was happy to note that the database program also had functions that allowed him to get lists of when maintenance was due on systems, and even to print out permit renewal applications.

Besides the permit data, AIM fed other information into the database. Water meter information was fed in for those parcels on municipal water—which was most of them. Where permit data lacked the assessor's parcel code, the parcels were located through cross-checking the addresses with the information on the city assessor's parcel map, which had previously been digitized. All this information was mated with pre-existing GIS data on soil types, surface waters, depth to groundwater, and other data.

Jerry set about designing a program to ensure that The Zone was meeting the performance standard of no surfacing effluent. Their data on permits included some information on repairs that he could have used to form hypotheses about where surfacing effluent was most likely. However, Jerry thought that the decision to repair a system was too much a matter of happenstance, depending on how observant or conscientious a system owner was, or whether a neighbor reported surfacing effluent. He decided to start with a blank slate and get his information about surfacing effluent from new condition assessments.

They did not have resources to inspect all the systems during the next spring wet season, so Jerry decided to use the GIS system to try to find parcels more likely to have surfacing effluent, so that they could be sure to inspect those during the wet season in the spring. He guessed that older soil absorption systems, and those on shallow soil, were more likely to fail. When he asked AIM to produce a map showing the older systems on shallow soil, they pointed out that there were contradictions between the soils information from individual parcels and the data in the GIS soils layer from NRCS data. That was not surprising, since the resolution of the NRCS map was much coarser than the parcel size in town. After some discussion, AIM and Jerry decided to use the soil data for the SAS from the permits where that was available. For parcels that did not have permit data or soil tests, they decided to use a combination of NRCS data and interpolation of adjoining parcels' permit data—again, where available—to make a best estimate of the actual conditions.

Since they had water-use data for many of the parcels, Jerry and AIM decided to focus, too, on the parcels with water use of greater than 75% of design flow over any two-month billing period. They figured that this high level of consumption meant that design flow was probably exceeded on at least some days. Many of the residences were occupied only on weekends or seasonally, or were rented out by the week, which Jerry and AIM thought increased the likelihood that a high water use over two months reflected greater-than-design flows during parts of that time.

(Continued on next page)

AIM produced a number of colorful maps showing the parcels with older systems, the parcels with shallow soil, the ones with high water use, and a composite map. The systems on shallow soil tended to be older ones, so they were doubly indicated to be underperforming.

The preliminary analysis identified 603 parcels as having one or more indicators of systems likely to have surfacing effluent. Jerry thought he could inspect about 100 systems the first year during the three-week period that was most likely to have saturated soils and surfacing effluent. Even just counting the older systems on shallow soils, they found 315. He needed a way to narrow down the list.

Jerry and Ray, the health officer, both looked with annoyance at the map on the wall, summarizing the GIS analysis. “Six hundred parcels, six years!” exclaimed Ray. “With our beach warnings and closed shell fisheries, people are going to demand faster action than that. If that’s the number of parcels that need to be fixed, we need to get more resources or figure out a faster way to inspect the systems. The drive to put in sewers is going to pick up steam when people find out how much needs to be done with the onsite systems.”

“It’s a lot of parcels,” agreed Jerry. “Still, putting in a sewer isn’t going to take fewer resources or go any faster than addressing the issues on these parcels. You know at least as well as I do all the costs and complications associated with the sewer.” Ray nodded. “Still, I see your point—six years is a long time to get around to all these parcels. The thing is, Ray, we need to keep straight that these are not problem parcels we have identified. They have the potential for problems. That is, they have the potential to have surfacing effluent. We don’t know how many of them actually do have surfacing effluent, ever.”

Ray knew how the analysis had been done. “Right, we could inspect 100 in the spring and find 5, or 95, with surfacing effluent. We don’t know until we’ve made the inspections.”

“What’s important is both how well or poorly the systems are performing and how much their performance is affecting the waters. I’ve been reading this handbook on reliability that Valerie gave me. There’s something called failure modes and effects analysis described in there. FMEA is way too complicated for us to use in its entirety for now, I think. It involves figuring out all the ways the systems could fail and what their effects would be. I’m thinking that we could use the effects part of the analysis to narrow down the number of systems we inspect in the first round. Which of these 603 parcels are most likely, if they have surfacing effluent, to be affecting water quality?”

Ray was ready with a good guess. “Those closest to the water, I suppose.”

“It seems reasonable,” Jerry agreed. “We haven’t proven it, but it seems a reasonable hypothesis. So which of these 603 systems are closest to the water? Those are the ones we concentrate on in the spring.”

“By ‘the water,’ I suppose we mean any surface water, right?” asked Ray. “Whether a system is near the bay, near Fish Brook, or near smaller tributaries to the bay or the brook, it’s going to be contributing to the indicator bacteria detections, agreed?”

“Agreed,” replied Jerry. “I’ll ask AIM to find the hundred or so systems of these 600 that are closest to surface water of any sort.”

(Continued on next page)

Barb from AIM put some new maps on the wall to show Jerry and Ray. "It's not easy to find the 100 of the originally identified 603 systems which are closest to surface water," she said. "We know where the surface waters are. We're less sure about the soil absorption systems. We included the as-built drawings in the database, so where the permits have as-builts, we know where on the parcel the system is. Trouble is, most of these earlier permits don't have as-builts. So we tried working with the house location, assuming that the SAS was somewhere near the house. These three maps show the results: There are 53 houses within 20 feet of surface water, 62 within 30 feet, and it jumps to 197 within 40 feet and 485 within 50 feet. I suppose we could tweak the analysis to find the magic number, say, 35.5 feet, that gives us 100 houses. But our resolution of the house location and of the location of the surface waters is too low to make that a really meaningful selection. You'd be almost as well starting off with the 62 houses identified as within 30 feet of water and add 38 or 40 houses randomly selected from the rest of the set of 197 houses within 40 feet."

Barb walked over to a fourth map. "Remember, the 603 systems include those which are constructed before 1980, those with less than three feet to groundwater or bedrock, and those with high water consumption. If we take the intersection of the three sets—the old systems on shallow soil where lots of water is being used—then there are 110 within 40 feet of water. That's the closest I could come up with, using assumptions I thought reasonable, to the 100 systems you're looking for."

Jerry and Ray looked at each other. "I hate to complicate things," said Ray, "but we could use those 197 houses within 40 feet of water. What if we did a quick inspection of all 197, just enough to locate the SAS and find out whether there was surfacing effluent? If we had more time, we could either go on to other systems and do the same thing, or go back and do more thorough inspections of some of the 197."

Jerry and Ray discussed the alternatives for a while and realized that they did not have much of a scientific basis for deciding whether they would find more surfacing effluent with thorough inspections of the 110 systems that had all three indicators of potential surfacing effluent or quick inspections of 197 systems with at least one indicator. In the end, they decided to go with the 110 systems, because they knew that it was less work to communicate with 110 homeowners than 197.

(Case Study continues on page 5-39…)

5.5 Failure Modes and Effects Analysis

Those who believe Murphy's law— "Anything that can go wrong, will go wrong"—will see the value of failure modes and effects analysis (FMEA). FMEA is a method that documents all the potential ways failure can occur in a product, a process, or a component and what the effects are. FMEA also identifies maintenance procedures that could be used to reduce or eliminate the potential failures (Ireson *et al.* 1996). The method has been used in the automotive, civilian aircraft, and electrical power industries, among others (Ireson *et al.* 1996; Moubray 1997; Drake 2004). Jones *et al.* (2004) detailed how FMEA could be applied to decentralized wastewater treatment.

FMEA has a broader focus than the other reliability tools discussed in this handbook. To keep the discussion simple, two performance standards were used to illustrate the other reliability tools: no surfacing effluent and nitrate-N levels under 20 mg/L before soil dispersal. In contrast, FMEA depends on a step that identifies all the performance standards for a system and all its components, so that all the conceivable functional failures can be identified. Identifying all the performance standards for a system and its components can take a third of all time expended on a reliability assessment and improvement process (Moubray 1997).

The simplest FMEA identifies potential failure modes (ways in which functional failures can occur[8]), potential causes of each failure mode, and the effects of each failure mode, including a qualitative rating of severity. FMEA can also include quantitative measurements or calculations of severity and probability of each failure mode (Jones *et al.* 2004). A given component can have many functions, and for each function it may have multiple failure modes. For example, Jones *et al.* (2004) describe a functional requirement of the house sewer line as "Move wastewater from house to septic tank," which could be refined to "Move wastewater from house to septic tank rapidly enough to promote rapid drainage from sinks, toilets, etc." (The drainage speed could be quantified, as well.) Functional failures occur (Table 5-6) when the sewer line

- Does not conduct any wastewater (a blockage)
- Conducts wastewater so slowly that drainage is slow or there is a backup into the house (a partial blockage)
- Conducts some or all of the wastewater somewhere other than to the septic tank (as with a leak or rupture)

Each functional failure, in turn, may have multiple failure modes or causes. In FMEA, both these failure modes and the effects of the failure are documented (Moubray 1997). Failure effects that may be considered include sickness, injury, or death to people; violation of regulatory mandates; environmental damage; and economic impacts.

Based on the analysis of failure modes and effects, together with knowledge of the costs and effects of preventive and corrective maintenance, it is possible to decide what action to take—if any—to prevent failures. Each possible maintenance action can be matched with the effects of failure that may arise from not performing the maintenance action, giving a basis for deciding whether the maintenance action is worth doing (Moubray 1997). This qualitative application of FMEA can identify where the worst failure effects may arise.

More helpful for decentralized wastewater is FMEA's ability to highlight where hidden failures could take place, so testing for the hidden failures could be incorporated into maintenance routines. For example, if a high water alarm in a pump chamber fails, the failure may never be noticed. But if the pump fails, too, the effluent may flow out around the pump chamber and never reach the soil absorption system. Performing FMEA would identify the loss of the alarm as a possible failure and highlight the need for consideration of maintenance routines that would detect the loss.

[8] Different authors use the term "failure mode" differently. This discussion follows the treatment of Jones *et al.* (2004).

Conversely, run-to-failure could be identified through a qualitative FMEA as the preferred option (Moubray 1997). Run-to-failure is the preferred option when the consequences of failure are acceptable, that is, when

- The effects of a failure mode are not critical to human health or the environment
- All of the following tasks are too expensive or not technically feasible:
  - Detection of incipient failure
  - Scheduled restoration work
  - Scheduled (pre-failure) discard work

Table 5-6
FMEA Analysis of One Function of the House Sewer Line

Component Function	Failure Mode	Cause of Failure	Effect of Failure
Move wastewater from house to septic tank rapidly enough to promote rapid drainage from sinks, toilets, and other areas	No wastewater conducted	• Too many bends in sewer line • Excessive use of garbage disposal • Fats or grease plug line • Large foreign object is flushed • Sewer line is too small • Sewer line has too little or negative pitch	• Potential for direct contact with pathogens; sickness • Wastewater remains in house, causes property damage • Repairs necessary (monetary cost)
	Too little flow	• Too many bends in sewer line • Excessive use of garbage disposal • Fats or grease plug line • Large foreign object is flushed • Sewer line is too small • Sewer line has too little or negative pitch	• Potential for direct contact with pathogens; sickness • Wastewater remains in house • Inconvenience from slow drainage • Repairs necessary (monetary cost)
	Wastewater conducted somewhere other than septic tank	• Leak or rupture	• Potential for direct contact with pathogens; sickness • Wastewater remains in house • Damage to foundation of source structure • Repairs necessary (monetary cost)

Adapted From Jones *et al.* (2004)

Qualitative ranking of the frequency (probability) of occurrence of a failure mode and the severity of its effects can be done without quantitative studies (Jones *et al.* 2004), to form a table similar to Table 7-7 described in Section 7.5 on risk-cost. Indeed, this aspect of FMEA is conceptually quite similar to risk-cost.

FMEA can be made quantitative with the help of probabilities derived from failure curves (Section 5.3). Jones *et al.* (2004) suggest no further quantification of the severity of effects than ranking on a severity scale from 1 to 10, with concise definitions of what each number on the scale means operationally. With the help of this sort of quantification, FMEA can be used as the backbone for deciding on capital expenditures and maintenance procedures.

5.5.1 Uses of FMEA

The daunting aspect of FMEA for the decentralized wastewater field is how much up-front work it requires. Moubray says that with "reliability-centered maintenance," which has FMEA at its heart, "[m]ost applications pay for themselves in a matter of months, although some have paid for themselves in two weeks or less" (Moubray 1997, p. 292). He is talking about industrial applications, for example, in civil aviation, where capital expenditures, cash flow, and industry concentration are very high compared with decentralized wastewater. FMEA has been endorsed for centralized wastewater treatment systems, as well (Fortin *et al.* Undated). When a large decentralized service provider has responsibility for thousands of systems, however, the scale of operations—and, thereby, cash flow—is orders of magnitude smaller than for large centralized systems. Even in the electrical power industry, FMEA was applied systematically only after governmental pressure to do so and when many utilities pooled their resources to form a common research institute (Drake 2004).

Applying FMEA to Decentralized Systems

Wastewater draining from the house is a function of any system. In this example, wastewater failing to drain from the house is the failure mode. All possible failure causes are considered; perhaps there are many, from crushed pipes to failed pumps. In each case, property damage is a real, likely effect. Human health impacts may also occur.

Pipes are rarely crushed; even if they are, predicting such an occurrence is difficult. Thus, preventive action is not warranted. However, pumps do fail and are accessible. Inspecting them, installing alarms that warn of a failure before damage occurs, and other actions to prevent failure or reduce its consequences could be taken. Each of these actions is likely less expensive than repairing a system in which a pump has failed without being replaced quickly.

The effort necessary to carry out an FMEA on each system means that it is most attractive to organizations that work with large numbers of the same type of reasonably complicated system. Conventional onsite systems, consisting of a septic tank and a gravity-fed soil absorption system, are simple and relatively well understood. They have few or no moving parts to break and decades of field experience distilled into recommended procedures on troubleshooting and maintenance (for example, Adams *et al.* 1998; Consortium of Institutes for Decentralized Wastewater Treatment 2004). Systems that integrate active components, like pumps, blowers, and control panels, have a greater failure probability than those with solely passive components (Frodsham and Cardew 2000 as cited in Jones *et al.* 2004).

Any company manufacturing a large number of wastewater treatment components or systems that integrate electrical and electronic components may wish to apply a simple FMEA in the design phase, to find and reduce the number of potential failure modes. Providing good advice on maintenance routines is in a manufacturer's interest, as it preserves good system performance and, therefore, the manufacturer's reputation. Those companies that have closest contact with their distributors, installers, and O&M providers have a network of people who can provide the field-based feedback on component performance that could help the company improve recommended routines for the installers and O&M providers, and which may lead to improvements in the product design.

Similarly, if an RME is managing thousands of advanced wastewater treatment systems of the same type, especially in an area where soil conditions are fairly uniform, then it may be worthwhile to understand all the ways in which that system can fail and how (or whether) to prevent the failures. An RME profits by reducing O&M costs. Even if they do not choose to perform a full-blown FMEA, the RME management may wish to carefully track the maintenance they perform and include information on failure modes and effects in their database. This database could be analyzed to find ways to reduce the O&M expenditures without sacrificing service levels.

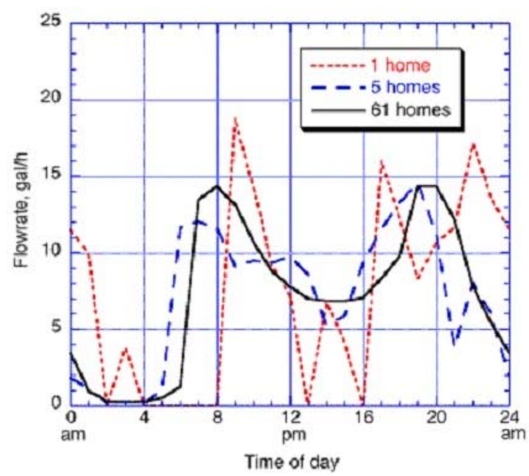
While there are barriers to applying full-blown FMEA to decentralized wastewater, the Failure Analysis Chart for Troubleshooting Septic Systems (FACTSS) provides an overview of failure *modes* for conventional onsite systems (Adams *et al.* 1998). FMEA work could build on this start.

5.6 Process Reliability

It is possible to be in compliance with a wastewater treatment effluent standard even while exceeding it, if the standard is written to take process reliability into account. Writing a standard in terms of process reliability recognizes the variability in wastewater treatment processes and specifies how often the system is allowed to exceed the standard.

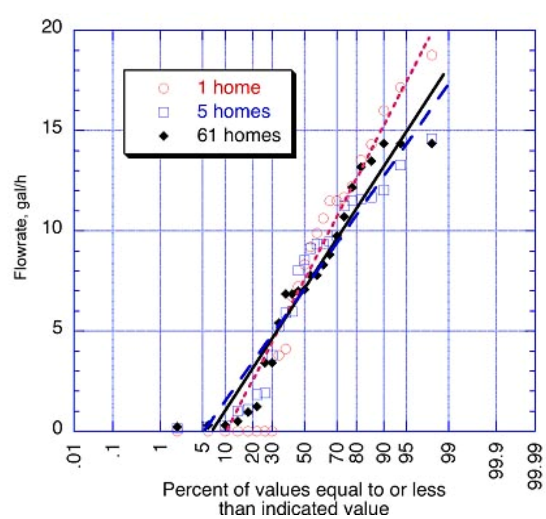
The effectiveness of treatment processes varies because of variations in influent flow, temperature, and constituents; variations in performance of mechanical equipment; variations in biological processes; and other factors. The variation in performance of wastewater treatment processes using biological systems can frequently be described with a log-normal distribution. When this is the case, a statistical (coefficient of reliability) or a graphical tool can be used to find the mean design value that will allow the system to achieve a certain level of treatment X% of the time. The graphical tool can also be used to display the variation in results in a way that makes the level of reliability transparent. These tools can be used for both the nitrogen performance standard and the performance standard forbidding surfacing of effluent, as well as for many other possible performance standards.

The graphical tool is easiest to explain. Consider flow rates of effluent measured throughout the day in one, five, or sixty-one homes (Figure 5-12 and Figure 5-13). Displaying hourly flow rate versus time of day gives a good picture of when the variations take place, and it is easy to guess what types of water uses might be contributing to the flows at different times of day. However, the figure does not give a clear sense about how often various hourly flow rates occur.



(Tchobanoglous 2003)

Figure 5-12
Hourly Flow Rates Measured over a 24-hour Period



(Tchobanoglous 2003)

Figure 5-13
Hourly Flow Rates Versus Percent of All Values Less Than or Equal to That Flow Rate

If the user's task is to design a wastewater system that can handle variations in the hourly flow rate, then a more useful display is found in Figure 5-12. In the figure, the X-axis has been transformed to be the log of the percent of values that are at or under the given flow rate. For all three sets of homes, for example, 50% of hourly flows are at or under 7.5 or 8.0 gallons per hour. From inspecting the red line with short dashes Figure 5-12) shows that a system for one home designed to handle a maximum hourly flow of 17 gallons would be 95% reliable. That is, for 95% of the hours measured, the flow rate would be at or under the maximum the system was designed to handle. To achieve 99% reliability, a design value of 21–22 gallons per hour would be necessary. (In practice, the system would be designed for a maximum daily flow, or even flow over a couple days, but the principles of the analysis are the same.)

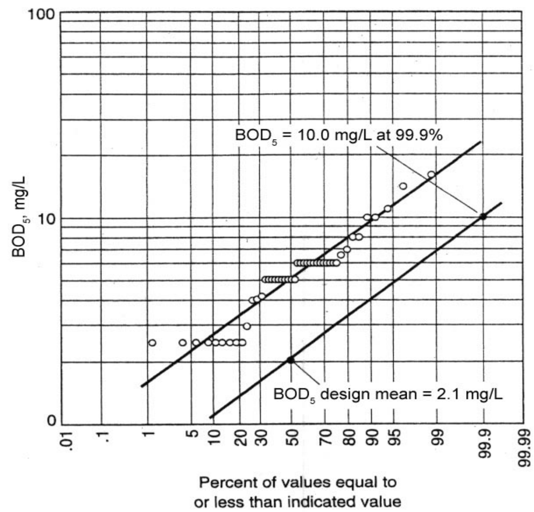
Model Onsite Performance Code

The National Onsite Wastewater Recycling Association (NOWRA) is developing a "Model Onsite Performance Code" that incorporates process reliability data. The code is intended to be useable by state or local authorities in setting performance standards for their jurisdiction. They will be able to use a database of process reliability results to evaluate whether a given technology meets those performance standards. See section 3.3.1 for more details.

For data sets where N (number of data points) is large or very large, then the graphical method is not necessary. In a spreadsheet format, the data can be arranged in order of value and the value at any given percentile can be found directly. There are several advantages to displaying the data graphically where N is not large. First, for data distributed log-normally, the log scale of the percent on the X-axis allows a straight line to be drawn through the data. In Figure 5-13, the straight line for the one-house data (red, short dashes) can visually be extrapolated to 99% or 99.9%, even though there are only 24 data points. Plotting the data also allows the eye to see trends that might be missed in blind application of a formula. In Figure 5-13 the black, solid line for the 61-home data set shows that 99.9% of all hourly flows are 18 gallons/hour or less. Looking at the data themselves, however, it seems that the trend might not be a straight line from the 70% mark and to the right: rather, the hourly flows seem to approach a limit closer to 15 gallons/hour. Before investing a lot in a solution capable of handling higher hourly flows, the designer might want to gather more data to see whether 15 gallons/hour might give 99.9% or greater reliability.

Whether N is small or very large, the graphical display of the data makes it easy to understand the importance of the slope of the straight line fitted to the data points. If dollar costs of achieving a given level of treatment (or, in this case, of handling a given flow) are displayed directly on the Y-axis, then it can be easy to appreciate how much extra it costs to achieve each higher level of reliability.

The graphical approach can also be used to find the design mean necessary to achieve a certain level of reliability. For example, in Figure 5-14, the distribution of effluent values for BOD_5 for a treatment process is known and displayed in the upper line. This same treatment process is to be used to achieve a maximum effluent BOD_5 of 10.0 mg/L with a reliability of 99.9%, that is, it is not exceeded more than one day approximately every three years. The treatment process to which the data set corresponds produces an effluent of 10.0 mg/L BOD_5 with 90% reliability—the 10 mg/L line from the Y-axis intersects the line fitted to the data points at the 90% line from the X-axis. To find the design mean for the same treatment process dimensioned to achieve 99.9% reliability, place a point on the graph corresponding to 10 mg/L and 99.9% reliability. The treatment process is assumed to have the same variability of performance, so a straight line is drawn through that point, parallel to the straight line fitted to the data set. The new design mean is where the new line intersects the 50% value, or about 2.1 mg/L.



(Metcalf & Eddy 2003)

Used to Calculate the Design Mean for the Same Treatment Process Dimensioned to Achieve 10.0 mg/L BOD_5 at 99.9% Reliability

Figure 5-14
Probability Distributions for BOD_5 in Effluent rom a Treatment Process

A similar process can be used for a nitrate-nitrogen performance standard, as Jerry and Valerie discuss in the fictional case study (see the text box beginning on page 5-40).

The reasoning can work in the other direction, too. With the knowledge that 99.9% reliability in achieving 10 mg/L BOD_5 requires a design mean of 2.1 mg/L, a regulator might be convinced to reduce the reliability requirement to 90%, with a resultant design mean of 5.0 mg/L, if the costs for achieving 5.0 mg/L were shown to be significantly lower.

The examples thus far have been for parameters that vary continuously. For binary (pass-fail) parameters, the graphical method can be used if the Y-axis is time to failure. For example, if the Y-axis is time to failure of a SAS, then the graph could be used to set a minimum inspection interval. Say it was determined that most or all failed SASs were not reported to the regulatory authority. Then a standard of reliability could be set, for example, no more than 10% of all systems will be failed at any given time. From the line fitted to the data points, refer to the time (Y) axis to determine how long after installation 10% are likely to be failed.

5.6.1 Using Coefficient of Reliability to Find Mean Design Value

For calculating the design mean necessary for a treatment process to achieve a value at a certain level of reliability, the statistical method of coefficient of reliability can also be used. This section is drawn directly from Metcalf & Eddy (2003), explaining the method of Niku *et al.* (Niku *et al.* 1979; Niku *et al.* 1981).

$m_d = (COR)X_s$

where m_d = mean design value for the parameter (for example, total nitrogen in mg/L)
X_s = the standard (in the same units) that is to be met at a certain reliability level
COR = coefficient of reliability (unitless)

The coefficient of reliability is calculated with the equation

$$COR = \left[\left(V_x^2+1\right)^{1/2}\right]\exp\left\{-Z_{1-\alpha}\left[\ln\left(V_x^2+1\right)^{1/2}\right]\right\}$$

where V_x = coefficient of variation of the existing distribution = σ_x/m_x
σ_x = standard deviation of performance values from a treatment process
m_x = mean of performance values from a treatment process
$Z_{1-\alpha}$ = number of standard deviations away from mean of a normal distribution
$1-\alpha$ = cumulative probability of occurrence (reliability level)

Values of $Z_{1-\alpha}$ at different levels of cumulative probability are listed in Table 5-7 below. The second table (Table 5-8) lists values of COR for performance values exhibiting different coefficients of variation and at various levels of probability that might be used.

Table 5-7
Values of $Z_{1-\alpha}$ at Different Levels of Cumulative Probability

V_x	Reliability, %							
	50	80	90	92	95	98	99	99.9
0.3	1.04	0.81	0.71	0.69	0.64	0.57	0.53	0.42
0.4	1.08	0.78	0.66	0.63	0.57	0.49	0.44	0.33
0.5	1.12	0.75	0.61	0.58	0.51	0.42	0.37	0.26
0.6	1.17	0.73	0.57	0.54	0.47	0.37	0.32	0.21
0.7	1.22	0.72	0.54	0.50	0.43	0.33	0.28	0.17
0.8	1.28	0.71	0.52	0.48	0.40	0.30	0.25	0.15
0.9	1.35	0.70	0.50	0.46	0.38	0.28	0.22	0.12
1.0	1.41	0.70	0.49	0.44	0.36	0.26	0.20	0.11
1.2	1.56	0.70	0.46	0.41	0.33	0.22	0.17	0.08
1.5	1.80	0.70	0.45	0.39	0.30	0.19	0.14	0.06

(Niku *et al.* 1981)

Table 5-8
Listing of Values for COR

Cumulative Probability $1-\alpha$	Percentile $Z_{1-\alpha}$
99.9	3.090
99	2.326
98	2.054
95	1.645
92	1.405
90	1.282
80	0.842
70	0.525
60	0.253
50	0

(Niku *et al.* 1981)

Jerry explained the plan for quick inspections to Valerie, who liked it. While they were talking, Jerry mentioned the work he was doing for Scott, looking at the cost of owning and operating all wastewater treatment systems put into Scott's subdivision. "I'm a little nervous about having my rates regulated by the PUC," Jerry confessed, "but I think I can develop a rate structure that works."

"Ah, then there's one thing you ought to know," Valerie said. "The Department is working on a new standard for nitrogen. The draft legislation will make it mandatory for all new systems within a half mile of certain surface waters—we're still working out which waters those will be—to achieve 30 mg/L nitrate-nitrogen before distribution of the effluent. All this concern about hypoxia, you know. I don't know what the timing of the subdivision is, but if the law is passed this legislative session, many or all of the systems in the subdivision may be subject to it."

Jerry tried not to look disappointed. He thought, "There go all the calculations I've done so far." "How is the 30 mg/L going to be measured and enforced?" he asked.

"Not on the individual system, at least," Valerie explained. We're looking at permitting types of technologies which we are confident achieve the standard. I've been reading some studies that show you can get quite representative numbers by taking several grab samples, say four, from each of a small number of systems, say 20 to 40. Those numbers are a lot more representative than many samples from the same system, apparently. Of course, we want to make sure the individual systems are properly operating once installed. We're not sure yet what sort of monitoring we want to require. Any thoughts?"

"Well, monitoring is one thing," Jerry began. "Let's talk first about what 30 mg/L means. What proportion of the time do you expect the systems to meet 30 mg/L?" Valerie thought it was a strange question. "Why, all the time! That's the standard. It's like speeding. It's illegal to go over the speed limit. Sure, troopers will probably not choose not to pull you over if you exceed the speed limit by a little, but they don't try to find out how often you've exceed the speed limit. If they've nailed you once, they've nailed you."

"That's all very well and good for speeding," Jerry said. "Wastewater treatment is different. In normal operation, systems perform within a certain range. We design systems around a mean, and the output varies about that mean. The range of variation can be quite large, in fact. The data tend to be log-normally distributed. Here, let me show you." Jerry got a sheet of log-probability paper out of his briefcase and drew a graph like Figure 5-15.

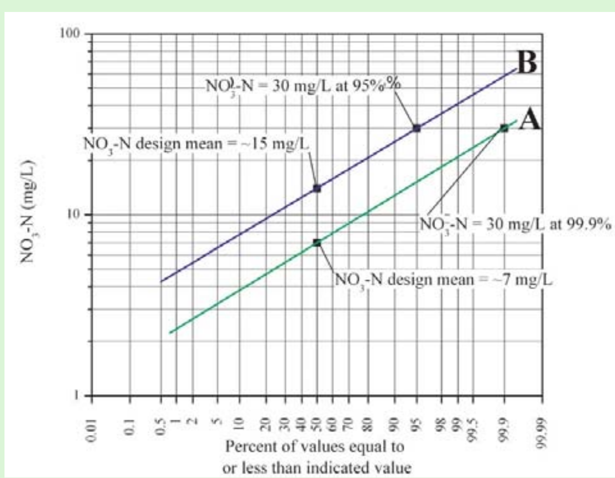


Figure 5-15
Graph Illustrating the Importance of Specifying the Percentage of Exceedances Allowed

"Look at line A, here. That represents a system which achieves 30 mg/L nitrate nitrogen 99.9% of the time. Not perfect, but close. Follow the line back to the 50% mark on the horizontal axis. That shows the mean we'll aim for in our design: 7 mg/L. Does it seem excessive to design for 7 mg/L to achieve 30?"

Valerie was unsure. Jerry continued. "Say we achieve 30 mg/L 95% of the time, backing off only about 5%. Line B shows what happens when we do that. It's the same slope as line A, because it's the same process, with the same variability. But it intersects the 50-percentile line at about 15 mg/L. It costs a lot less to design for 15 mg/L than for 7."

Valerie looked thoughtful. "That's definitely not a factor we've considered in our discussions. Do you have something in writing I could show my colleagues?"

"Sure. I have a five-pound tome that lays this out pretty clearly." Jerry smiled at Valerie's expression. "Don't worry, the section on these concepts is just a small part of it. I'll lend it to you."

(Case Study continues on Page 7-12…)

6 COSTING PRINCIPLES

This chapter contains information about generic costing principles and important costing concepts. While the principles and concepts are part of standard engineering economic theory, it is not unusual for them to be ignored or overlooked in practice. The costing tools presented in Chapter 7 provide meaningful analysis only when these principles and concepts are adhered to. Four principles affect the way costing tools are applied and the usefulness of their application:

1. The time value of money
2. What costs are included or excluded (both in terms of life-cycle stages and in whose costs are considered)
3. Uncertainty and risk
4. Granularity

These principles, their importance, their effect on costing calculations, and when to apply them are described in the following sections. Although these principles are seemingly simple, they are rarely applied consistently in costing analyses even though they significantly affect the results.

6.1 Time Value of Money

The real value of money changes over time. If alternative wastewater solutions are compared over long time periods, this change in value is likely to be significant. Even over relatively short time periods (as little as three years), accounting for the time value of money can influence the costing analysis and associated decision-making.

As an example, $1,000 received today would be worth $1,050 next year if it were invested at an interest rate of 5%. Similarly, $1,000 received next year is only worth $952.38 now if banks are offering 5% interest. A rate called the discount rate is used to account for this change over time. Many different methods exist to estimate appropriate discount rates (for further information see US EPA 2000a). A good starting point for "real" values for a public agency investing in wastewater infrastructure is 2% for a 10-year period and 3.5% for a 30-year period[9]. However, context and timing are important, and sometimes values as high as 5 or 6% over 20 years are used. For a private individual, the discount rate may be significantly higher.

[9] Current real and nominal discount rates are at http://www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html

The time value of money is different from, but related to, inflation. Inflation causes prices of goods to increase over time and thus reduces the buying power of money. Inflation is often ignored in economic analyses because it is not easy to predict price fluctuation or market interest rates. Sometimes the inflation rate is taken into account, and in this case the discount rate is “real.” If the inflation rate is not taken into account, then that discount rate is “nominal.” In more sophisticated analyses, escalation rates account for variations in cost increases in different sectors (for example, labor or materials).

The following formula translates a single cost that occurs in the future to its equivalent cost today, which is called Present Value (PV) or present worth:

$$PV = C_n(1 + X)^{-n}$$

Where PV is the present value of a future cash flow
X is the discount rate
n is the specific year that the cost occurs
C_n is the nominal cash flow in n^{th} year

The Importance of Accounting for the Time Value of Money

Seven options were considered to provide a wastewater treatment solution in the town of Warren, Vermont. These options had estimated total capital project costs varying between $4,692,000 (Option 7) for the cheapest and $5,069,000 (Option 1) for the most expensive. The comparison between the seven options was based directly on these figures (without any adjustment for the time value of money) and a set of other factors. The choice ultimately made was Option 7, mostly due to the heavy weight given to capital cost in the rating and ranking procedure used.

It is only fair to compare total project costs in the way that was done for Warren, without taking into account the time value of money, if capital costs are all to be paid within a single year. In practice, capital works payments typically occur over periods of three or four years. The table below shows how the present worth of the most expensive option changes if the costs are spread over time.

Table 6-1
Net Present Value of Capital Costs for Different Payment Regimes for Option 7

Payment Regime	NPV	Year 0	Year 1	Year 2	Year 3
Payment in one lump sum up front	$5,069,000	$5,069,000	$0	$0	$0
Payment in two equal parts over two years	$4,908,739	$2,534,500	$2,534,500	$0	$0
Payment in three equal parts over three years	$4,755,234	$1,689,667	$1,689,667	$1,689,667	$0
Payment in four equal parts over four years	$4,608,163	$1,267,250	$1,267,250	$1,267,250	$1,267,250

Annualized cost is another way of accounting for the time value of money. It is most effective when actual annual expenditures are similar from year to year. It makes costs that occur in one time period comparable and is useful for analyzing non-monetary benefits, such as reductions in health risk where benefits are constant over time. In some cases, annualized cost can be calculated without a discount rate. For example, costs of $30, $50, and $70 incurred in Years 1, 2, and 3 represent an annual cost of $150 ÷ 3 = $50. In other instances, where the time value of money is important, annualized costs can be calculated using a discount rate (from US EPA 2000a):

$$AC = PVC \times \frac{r(1+r)^n}{(1+r)^n - 1}$$

Where	*AC*	is the annualized cost accrued at the end of each of n periods
	PVC	is the present value of costs
	r	is the discount rate per period
	n	is the duration of the time period under consideration

Accounting for the time value of money using annualized costing is complicated if cash flows are irregular in timing and size. Using present value to account for the time value of money is an easy way to overcome this difficulty, as the exact cash flow can be directly inserted into the appropriate year. Standard texts on engineering economics or capital project analysis (for example, Fleischer 1984; Smith 1987) provide more information about understanding the time value of money using both of these techniques.

6.2 Which Costs Are Considered

Decisions about what costs are included or excluded in an analysis can significantly affect the analysis results. There are two important dimensions when considering which costs to include: **when** the costs are expended (that is, the time dimension) and **by whom** (that is, the stakeholder dimension). Using a “life cycle” approach addresses the time dimension and can help with decisions about what to include and exclude. Consideration of different cost perspectives in the stakeholder dimension allows explicit inclusion or exclusion of costs to different parties.

Externalities are costs that are difficult to understand in monetary terms. Dealing with externalities is particularly important because cost analyses often involve a trade-off between a risk (or externality) and a cost. The idea of externalities is discussed, and some ideas are provided about accounting for non-monetary benefits or losses, such as environmental and social costs.

6.2.1 Life-Cycle Approach

A common error made in costing analyses is to be inconsistent about which stages in a life cycle are included in an analysis. Another related error is to compare options over different time periods. Consistency in the time dimension is key.

Best practice approaches use a "life-cycle approach" because it provides fairer comparison in the long term. Costs from all life-cycle stages are considered. Alternatively, individual stages can be explicitly included in or excluded from the analysis.

For instance, an RME might investigate the pump replacement for their systems. The life-cycle approach encourages them to include not just costs incurred today, but also likely future costs. Specifying a larger pump might mean that it would require fewer inspections than a cheaper, smaller pump. In considering the whole life-cycle, the cheapest option over the long term is identified by accounting for both capital and operating costs, rather than focusing on reducing only capital costs.

6.2.2 Cost Perspectives

Analyses often only include costs that directly affect the party conducting the analysis. For instance, the operator of a set of systems replaces a broken pump. The operator charges a specific fee to replace the pump, so to minimize costs and make maximum profit, he buys a low-quality pump even though it might not last very long. His costing analysis and decision includes only his own monetary cost, and does not include monetary and non-monetary costs to other parties.

Other parties incur costs (both monetary or non-monetary) that were ignored in this analysis. The homeowner in the above example will incur further costs when the low-quality pump breaks and she must pay for a new one to be purchased and installed. If the operator accounted for the homeowner's cost perspective in addition to his own, he might discuss these options with the homeowner, allowing the homeowner to compare the benefits and costs of investing a little more now versus paying a lot more later.

The Effect of Uncertainty Due to Fluctuating Prices

One example of how fluctuations in price over a period of years affects the outcome of an economic analysis is related to the decision between using remote telemetry or traveling to inspect onsite systems. Steep increases in gas prices might make telemetry a more attractive option.

Improving system reliability often depends upon the operator or other party making a decision based on multiple cost perspectives, including their own, the homeowner's, and perhaps those of other parties or of society as a whole. In many cases, there is no incentive for the operator to consider or include these other costs. The situation described in this example can be addressed through provision of incentives for the operator, or through regulations that stipulate a certain standard in the quality or specifications of materials or components. An RME taking a long-term community cost perspective might use its perspective to justify setting local component standards (for example, a minimum quality of pump).

For services that society considers to be a fundamental need, such as water supply services or wastewater treatment services, it is useful to consider the "least cost to society." If it is accepted that the service is necessary for all people, an analysis can determine how the service can be provided to all people at the lowest overall cost while keeping risk (public health, environmental, financial/economic, and technological) at an acceptable level. This is called an economic analysis. The first step is to reduce the overall cost to society by including costs incurred to each and every party involved. Ways are then found to assign costs to different stakeholders in society, such as the consumer, the practitioner, and the jurisdiction, so that each party is paying an acceptable price for benefits. Calculating the "least cost to society" can also include costs of environmental damage that are commonly excluded if costing is done from a single perspective.

If the "least cost to society" is investigated, it is far more likely that reliability will be given priority, or will at least be considered in decision-making. More reliable systems may be more expensive initially, but will incur lower future costs and less risk of damage to public health or ecological systems.

Cost perspective tests segregate and analyze costs incurred by a particular party to determine whether or not a program, option, or scenario would be beneficial. These tests were initially developed for economic analysis of demand-side programs and projects[10] and include five tests:

- Participant Test
- Ratepayer Impact Measure Test
- Total Resource Cost Test (and its variant Total Societal Cost Test)
- Program Administrator Cost Test (utility perspective)

> **What Happens When Externalities are Excluded?**
>
> In this example, exclusion of "externalities" impacted decision-making and led to an unfortunate decision. A village in an area of poor soils and a high water table needed to decide on which sort of new systems to install. Based on a costing analysis, they decided that the cheapest option was treatment systems with a direct discharge to a pristine river and chose to go ahead with this option. If, however, in their analysis, they had included the environmental risk and associated cost of direct discharge to a river, it is likely this option would have proved unfavorable and a different decision would have been made.

Considering **externalities** is an important part of being clear about whose cost perspective is included in the analysis. Costs to society include not only the cost of ensuring engineering reliability, but also the many environmental and social costs of inputs to and outputs from the wastewater treatment system over its life. Such non-monetary benefits and losses are often defined as "externalities" because they are external to the monetary system. They are difficult to evaluate precisely because their value is different for different stakeholders. Externalities are often left out of economic analyses. In many cases they exist in the form of a certain level and type of risk to the environment, a person, or society as a whole.

The danger of excluding externalities from a costing analysis is that a particular action may appear favorable, when in fact it will result in a negative effect or risk that was not contemplated. However, it is neither possible nor desirable to evaluate and cost every possibility that might occur. A boundary must be drawn that defines which costs are significant and important to include, and which costs are insignificant or so unlikely that they can reasonably be left out. It is important to realize that a line is drawn and that value judgments are made about what is

[10] For further detail please see *California Standard Practice Manual* (California Energy Commission and California Public Utilities Commission 2001).

included and excluded from an analysis. The same line can then be drawn for other options to ensure fair comparison and that the trade-off between risk and cost is made consciously rather than by default or accident.

There are three different ways of including externalities in decision-making. Monetary values can be assigned to each one, and they can then be included in the actual cost analysis. In this case, a life-cycle costing analysis becomes a "whole-life costing" analysis. This is done through a variety of valuation techniques,[11] many of which are controversial in their application. Externalities can also be considered as separate criteria in addition to cost. This is usually done through a technique called multi-criteria analysis, a form of which is the "ranking and rating" method often used by engineering firms to compare alternatives. An example of an externality that might be included in comparing wastewater options is the extent to which the system requires changes in user behavior from the "flush and forget" mentality that many people bring to their toilets. By this criterion, a centralized system would likely be most forgiving of "flush and forget," while composting toilets would be least forgiving and toilets in decentralized systems would be in the middle. The key is to use a consistent basis to compare different options and how they rate with regard to this criterion.

The third and fairly common way of coping with externalities is to consider them as constraints that confine the scope of the options analyzed so that the constraints are not breached. An example of this is a performance standard such as a nitrogen limit that must be met regardless of the type of system chosen for a particular situation.[12]

6.3 Uncertainty and Risk

Uncertainty is inherent in all cost analyses, although it is often left implicit. Unforeseen variations in future costs result in significant changes to key inputs for financial and economic analyses. Experience and good judgment can inform the level of uncertainty. Various quantitative methods are also available to support decisions.

Some guiding principles are useful when considering uncertainty and risk in economic analyses.[13] The most important point is that descriptions of all known key assumptions, biases, and omissions are provided. If possible, a sensitivity analysis should be performed on key assumptions.

Sensitivity analysis is a systematic method of determining the effect of variation in input parameters on the results of an economic analysis. The variables that are most important are

[11] For more information concerning valuation of environmental goods, Hanley and Splash (1993) give detailed information about valuation methods such as contingent valuation method, hedonic pricing method, travel cost method, and production function approaches. Shabman and Stephenson (2000) present the debates that take place about valuation. "Willingness to pay" has been used by the US EPA (2000b) in a study of water quality benefits from regulating confined animal feeding operations.

[12] US EPA *Onsite Wastewater Treatment Systems Manual* (US EPA 2002b) may be useful for this purpose, where Figure 3.14 presents a "probability of environmental impact decision tree."

[13] US EPA (2000) *Guidelines for Economic Analyses* provides additional information about analyzing and presenting uncertainty (pp.27–30).

selected, along with a range of plausible values for each variable, and the resultant changes in analysis results are examined. The effect of changes in two variables at the same time can also be examined. Identifying a "switch point" value, a condition at which a person using this analysis would change their decision (for example, where net benefits become net losses), may also be useful for decision makers.

Some of the different ways that uncertainty is integrated into economic analysis include methods like expected net present value (using mean and variance), use of standard deviation to measure risk, methods for assessing risk (scenario analysis, sensitivity analysis, Monte Carlo simulation), Delphi-type methods, and meta analysis.

Risk is important in cost analyses, and is related to uncertainty in the analysis and to the concept of reliability. Relevant risks can be characterized as financial risks or as environmental, socio-economic, or public health risks.

There are several ways of taking risk into account. The risks implicit in the choice of one option or another may be considered as an additional analysis to the costing analysis. This may be done through the use of the framework presented in Chapter 4, where risks are considered at various stages and decisions are made about acceptable risks. Alternatively, costs may be assigned to risks so that these costs are included in the costing analysis. This approach requires sensitivity analysis to account for the inherent uncertainty of risk prediction.

6.4 Granularity

"Granularity" refers to the relative size of the smallest object considered. For example, does the analysis consider performance of the onsite system as a whole, or consider the septic tank as a separate component, or even consider performance of the various parts (external walls, baffles, access risers, tees, or other parts)?

A detailed analysis requires large amounts of detailed data, and a balance must be reached between the usefulness of existing data and the cost of collecting new data. The level of detail in the data should adequately serve the purpose of the analysis. Over-investment in data collection is wasted time and money, while inadequate data may result in a meaningless or misleading analysis. For example, using system-wide cost averages hides local hot spots where investment in upgrades may provide better than average returns in risk reduction. Increasing granularity (that is, considering smaller objects in the reliability or costing analysis) is meaningful for model 4 or 5 RMEs, where business-side costs may vary widely on a geographical scale and use of particular costs will significantly affect where and how investments are most profitably made. Further information and exploration of granularity and similar concepts in the electricity industry is covered by Lovins *et al.* (2002).

7 COSTING TOOLS

This section introduces a variety of costing tools for informing decisions about reliability and cost of decentralized wastewater systems.

When these tools are initially applied, "best guess" estimates may be made for some of the costs and numbers in the analysis. As costs are tracked and an asset cost inventory is created, these estimates can be refined. It is better to begin with estimates and benefit from using the tools rather than waiting until all needed data are obtained. The tools to be used will determine the type and detail of data required. For example, asset cost inventories or databases connected with reliability data could be created and maintained by a practitioner (a pumper, installer, operator, or maintainer) concerning quantitative or qualitative information that they gather when they work on a system. If this information is computerized it will be more readily available to other parties. Such a database is a necessary foundation for most of the costing tools described in this handbook.

As mentioned earlier, life-cycle costing, activity-based costing, and risk-cost modeling are the most important tools for improving reliability of decentralized wastewater treatment systems. These three tools are the focus of this section. Other tools are presented in less detail, with additional references for readers seeking a deeper understanding.

7.1 Life-Cycle Costing

Life-cycle costing is used to assess the total cost of acquisition and ownership of a product. Often in decision-making for small wastewater systems, only a portion of the total costs of a technology or project is considered. Consideration of capital costs alone can lead to the selection of systems with low capital and high operating costs. High operating costs can be associated with:

- Costly repetitive maintenance
- High risk of failure resulting in expensive repairs
- Inefficient resource use (for example, high energy or water consumption)

How can this tool influence reliability of decentralized wastewater systems? Why is it worth using life-cycle costing, and what questions can it help answer? Here are some examples:

1. Which of several possible wastewater solutions should be chosen? Should a less complex system that will be easier to maintain be chosen? Is it worth building in redundancy and investing more in capital costs in order to reduce maintenance and repair costs?

2. What management, operation, inspection, and maintenance regimes will cost the least but give the greatest benefit in terms of reliability and reduced risk of a set of systems?

3. What is the most cost-effective approach to take towards repair, replacement, rehabilitation or life extension, and abandonment?

4. How are funds allocated towards different competing priorities?

5. What are the most significant costs associated with operating a particular type of system?

6. Would a demand management program be a cost-effective way to reduce hydraulic load on a system and therefore improve its reliability, or to reduce maintenance and pumpout costs?

Though the life-cycle cost (LCC) tool helps answer these questions, the data necessary for conducting the analysis is unlikely to be immediately available. This shortcoming may be overcome by making assumptions based on past experience, or by collecting the necessary data once the analysis scope is determined.

Calculating the cumulative cost of a product or system over its life cycle allows proactive decisions and wise investment by all major stakeholders. The LCC tool is a way to predict the most cost-effective solution over the long term.

The life-cycle phases commonly included are shown in Figure 7-1 below.

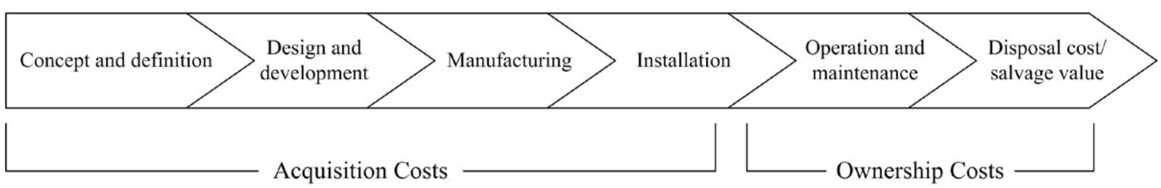


Figure 7-1
Commonly Used Life-Cycle Phases

Ideally, the optimization of LCC occurs at the design stage and accounts for all costs that will be incurred in a system's lifetime. Decisions about a system's design, manufacture, and installation may affect its performance, safety, reliability, and maintenance or support requirements, and ultimately determine its price and ownership cost. Decisions made early in a product's life cycle have a greater impact on the product's LCC than those made later. Life-cycle costing can also be used later in a product's life to inform decisions about resource allocation for repairs, upgrades, and replacement.

Life-cycle cost should not be considered separately from cash-flow analysis and methods of financing various options. The ultimate cost criterion is whether or not the cost is acceptable to those who will pay. This criterion is usually used as a form of cost-effectiveness analysis. Cost-effectiveness analysis reveals the best way to minimize the cost of achieving specific goals. It compares alternatives that all give the same benefit. This benefit is usually described in material rather than economic terms (for example, an 80% reduction in N concentrations).

Life-cycle costing may or may not include the externalities described earlier. If externalities (such as social or environmental benefits or losses) are assigned monetary values and are included directly in the costing analysis, then the analysis is called a "whole system life-cycle costing." If externalities are not included, they should be considered separately and included in decision-making with the results of a life-cycle costing exercise.

7.2 How to Use Life-Cycle Costing

The process of life-cycle costing involves several indispensable steps. For instance, jumping straight into the development of a life-cycle costing model without considering the aims and objectives of the analysis will lead to wasted work and unclear outcomes. Each step is described in the following sections.

7.2.1 Planning

Planning ensures that the question to be answered is clear and answerable. Life-cycle costing is a versatile tool that can be used in many different ways. For example, it may be used to:

- Compare design alternatives for their cost effectiveness
- Identify cost drivers (any cost element of the LCC that has a major impact on the LCC) and cost-effective improvements
- Compare use, operation, test, inspection, and maintenance strategies for their cost effectiveness
- Compare approaches for repair, replacement, rehabilitation/life extension, and abandonment for their cost effectiveness
- Allocate available funds among competing priorities
- Inform long-term financial planning

Once the question is clear, it should be refined using the following considerations:

- Define the analysis scope. For example, what "unit" is to be life-cycle costed: an individual component (pump, distribution box, or other component), or a complete treatment system including the leachfield? Which phases of a system's life cycle will be included: only the operating phase, or all phases from construction to disposal?
- Define the base case operating and maintenance support scenario
- Identify constraints and limitations, such as system performance and availability requirements or maximum capital that limits the options to be evaluated
- Identify alternative course(s) of action to be compared with the base case
- Consider the resources and data required to conduct the analysis
- Define a reporting and communication plan for the analysis results to support decision-making

7.2.2 Creating a Life-Cycle Model

A life-cycle model is an accounting structure that contains all the possible costs associated with a system over its lifetime, or with the particular phases chosen for analysis. A cost breakdown structure (CBS) is created to identify and articulate these costs systematically. Cost categories relevant to the analysis (for example, preventative maintenance costs) are identified and each category is separated into smaller components (activities, sub-activities, and other components) until each sub-activity can be distinctly defined and its cost easily estimated. Each of these costs is a “cost element.” The range of cost elements included in the life-cycle model will vary depending on the system of concern and the analysis objective.

The cost for a cost element may be estimated in a few different ways: engineering method, analogous cost method, parametric cost method, and bottom-up method. The data needed to estimate costs should be identified so that data sources may be chosen. For each cost element, it is important to include labor and energy costs. It is also important to identify uncertainties associated with the estimation of each cost element, as these impact the level of certainty that can be justifiably attached to the analysis result.

Various cost indices can help with estimating costs. Engineering firms commonly use these during the design and costing phase of a project. An example can be found at http://enr.construction.com/features/conEco/costIndexes/default.asp.

The range of operation and maintenance costs included in a comprehensive life-cycle analysis of a decentralized wastewater system is much larger than the set of costs normally included in estimating O&M costs.

The final stage of preparation is to simplify the analysis as much as possible. Some ways of doing this include:

- Eliminate elements that do not have a significant impact on the total LCC
- For comparative studies between alternative courses of action, identify and eliminate elements that will not vary between alternatives

Possible Management, Operating and Maintenance Costs in the "Operating and Maintenance" Phase of a Treatment System's Life Cycle

- Labor Costs: Includes salaries and benefits cost of personnel.
- Electrical Expense: Includes the cost of electrical power for system operation.
- Capital Replacement: A budget allowance to establish a sinking fund for future equipment replacement.
- Tank Pumping: The cost associated with pumping, trucking, and treatment of residuals from treatment tanks.
- Sampling and Monitoring: The costs of sampling and analysis of parameters required by permits. Includes sampling and analysis of influent, midstream waters, effluent, groundwater, or surface water, as well as biomonitoring.
- Regular Inspections: The cost for regular inspections required by installation or operating permits.
- Insurance or Liability Costs: The estimated annual premium for insurance on wastewater system components, or estimated liability costs.
- Training: The annual cost for training and continuing education for operators, maintainers, or other groups.
- Miscellaneous Repair: The estimated annual cost for miscellaneous equipment repair.
- Vehicle Mileage: The estimated cost for vehicle mileage on account of the system.
- Telemetry/Paging Service: The estimated annual cost for telemetry and paging service including telephone bill and paging service fees.
- Administration/Billing: The estimated cost for the operator to administer the management district and to undertake and manage billing.
- Annual Operating Fees: Any fee assessed by regulators for ongoing permit administration work.
- Materials and consumables.
- Engineering modifications.
- Software maintenance.
- Spare parts and repair materials, storage space, packaging, shipping, and transportation.
- Other tasks such as project management, cost/schedule management, or data management.
- Unavailability Costs: These costs are influenced by a system's reliability and maintainability; systems may be unavailable due to failure, human error, or preventive maintenance. Unavailability costs include the cost of corrective and preventive maintenance and the cost associated with loss of the system's function during the period of failure.
- Emergency Costs: These costs include preparation for responding to failures (for instance, the cost of having a spare pump on hand).

7.2.3 Analysis Using the LCC Model

The net present value (NPV) of different scenarios is calculated first. A specific time period must be chosen for the analysis so that comparisons between alternatives can be made on an equivalent basis. Based on the cost breakdown structure, the likely costs for a system (or group of systems) are estimated and projected over this timeframe, and the NPV of these costs is calculated.

The process described above enables a comparison of the total life-cycle costs for different systems, maintenance regimes, or monitoring strategies, depending on the analysis goal. Present value (or present worth) discounts each future cost back to its worth today. Calculation of “net” present values involves adding together the present value of all predicted future costs throughout the life of a system. It is calculated as follows:

$$NPV = \sum_{n=0}^{T} C_n (1 + X)^{-n}$$

Where *NPV* is the net present value of future cash flows
C_n is the nominal cash flow in n^{th} year
n is the specific year in the life-cycle costing period
X is the discount rate
T is the planning period (the full life cycle) in years

The life-cycle model can be used to compare scenarios, identify cost drivers, quantify differences between different alternatives, and categorize costs (such as fixed or variable costs, recurring or non-recurring costs, acquisition or ownership costs, and direct or indirect costs) relevant to the analysis users.

Some instances where it is important to use life-cycle costing and the net present value in thinking about onsite wastewater systems are:

- Comparing several possible wastewater solutions
- Comparing different O&M regimes

Sensitivity calculations may be used to analyze impacts of different assumptions, discount rates, and cost element uncertainties on LCC model results. Documentation of results should always clearly state the limitations and uncertainties associated with the analysis.

The following assumptions are used in the life-cycle costing example shown below:

- The regularly inspected tank may be pumped at 3-year, 4-year, 5-year, or even 10-year intervals[14].
- The planning period is 30 years.
- A “sludge judge” costs $500. One “sludge judge” is sufficient for the community, which has 184 systems. The distributed cost is $3 per household in the first year.
- The cost of inspections is 1.5 hours labor per system, including travel to the site ($60)[15].
- If risers and inspection ports are installed, the cost of inspection per system is 1-hour labor, including travel to the site ($40).
- Installation of a riser costs $500.
- The annual cost of administration per system is $5.
- Training costing $200 is needed for the person who does the monitoring.
- No regime leads to a greater or lesser probability of failure of the septic system.
- The discount rate is 3.5%[16].
- Costs that are consistent across options are not shown.

Three maintenance options with variations are shown in Table 7-1. The results of the analysis are summarized in Table 7-2. In Regime 1, the septic system is pumped out automatically every two years. In Regime 2, a “sludge judge” is procured and all systems are inspected annually. The costs associated with the resultant pumpout frequencies are considered for this regime. In Regime 3, risers and inspection ports are installed to facilitate system inspections, and costs are considered for two pumpout frequencies (5 and 10 years).

The cost of automatically pumping every two years is comparable to the cost of inspecting annually and pumping out every five years (with or without riser installation), a frequency consistent with expectations for monitored systems. However, there are significant non-monetary benefits to incorporating regular inspections. Monitoring systems regularly reduces risk of failure. Automatic pumpout of a system is unrelated to inspection, so a system that is pumped out on a regular schedule but not inspected could suffer unnoticed chronic or even acute failure. Riser installation allows greater opportunity for practitioners and homeowners to be more aware of the system’s state, thus reducing its probability of failure. Septage treatment is an issue in areas where existing wastewater treatment facilities (central sewage treatment plants) are at or near capacity. Adding unnecessarily to the volume of septage to be treated is undesirable. Finally, a performance record is created through the annual monitoring process that can be used to target maintenance actions. For example, households with frequent pumpouts can be identified and provided with education to help improve use of the septic system and reduce pumpout

[14] The range of pumpout frequencies is based on US EPA 2002: “If systems are not inspected, septic tanks should be pumped every 3 to 5 years depending on tank size, the number of building occupants, and household appliances and habits...”

[15] This time and cost estimate can be customized for the local travel, soil, and site conditions and may be significantly longer in some cases; particularly for the first visit when the tank must be located.

[16] Labor costs sometimes increase at a higher rate than inflation. If this is expected, then it should be reflected in the calculation. Such escalation of labor costs has not been taken into account in this example.

frequencies and risks. Such information is also useful for directing long-term efforts in improving onsite system reliability.

The results also show that, should pumpout frequency fall to as little as every 10 years (a possible scenario for lower occupancy or water-conserving households[17]), there is indeed a cost savings attached to regular inspection of about $550 per system over the 30-year time period. Such cost savings become significant if a set of systems and their cost to society is considered. A community with 100 such systems might save $55,000.

A sensitivity analysis was conducted to examine the effect of the choice of cost of pumpout in this hypothetical example, where the cost of a pumpout was changed from $255 to $300 (Table 7-2). Although the two costs differ by only $45, the impact on the analysis results is significant and makes clear that assumed costs used in the analysis must be carefully considered and predicted with the greatest accuracy and consistency possible. The change in pumpout cost did not materially affect the relative order of the life-cycle costs for different regimes, but it increased the possible savings. With more costly pumpouts, cost savings of $400 per system are possible even with five-year pumpouts for the inspected systems.

Table 7-1
Example of Cost-Effectiveness Analysis (or Life-Cycle Cost Analysis of the Operation and Maintenance Stage) for Three Different Maintenance/Inspection Regimes[18]

Operation and Maintenance	NPV	Year[19]									
		1	2	3	4	5	6	7	8	9	10
Regime 1: Pumpout every 2 years											
Septic Tank Pumping	$2,304.65	$0	$255	$0	$255	$0	$255	$0	$255	$0	$255
Inspection											
Training											
Administration/Billing	$45.19	$0	$5	$0	$5	$0	$5	$0	$5	$0	$5
Total	$2,349.84										

[17] Bounds (2003) shows that some tanks do not require pumping for up to 20 years.
[18] The assumption that a checked tank would need to be pumped every 4 years is based on the EPA manual (pp. 4-45): "If systems are not inspected, septic tanks should be pumped every 3 to 5 years depending on the size of the tank, the number of building occupants, and household appliances and habits..."
[19] Costs for the first 10 years of the 30-year planning period are shown in the table; however, NPV was calculated based on the entire planning period.

Table 7-1
Example of Cost-Effectiveness Analysis (or Life-Cycle Cost Analysis of the Operation and Maintenance Stage) for Three Different Maintenance/Inspection Regimes (Cont.)

Operation and Maintenance	NPV	Year									
		1	2	3	4	5	6	7	8	9	10
Regime 2a: Check yearly, resultant pumpout frequency on average every 3 years											
Septic Tank Pumping	$1,509.86	$0	$0	$255	$0	$0	$255	$0	$0	$255	$0
Inspection (including travel)	$1,106.42	$63	$60	$60	$60	$60	$60	$60	$60	$60	$60
Training	$193.24	$200	$0	$0	$0	$0	$0	$0	$0	$0	$0
Administration/Billing	$91.96	$5	$5	$5	$5	$5	$5	$5	$5	$5	$5
Total	$2,901.48										
Regime 2b: Check yearly, resultant pumpout frequency on average every 4 years											
Septic Tank Pumping	$1,068.84	$0	$0	$0	$255	$0	$0	$0	$255	$0	$0
Inspection (including travel)	$1,106.42	$63	$60	$60	$60	$60	$60	$60	$60	$60	$60
Training	$193.24	$200	$0	$0	$0	$0	$0	$0	$0	$0	$0
Administration/Billing	$91.96	$5	$5	$5	$5	$5	$5	$5	$5	$5	$5
Total	$2,460.46										
Regime 2c: Check yearly, resultant pumpout frequency on average every 5 years											
Septic Tank Pumping	$874.59	$0	$0	$0	$0	$255	$0	$0	$0	$0	$255
Inspection (including travel)	$1,106.42	$63	$60	$60	$60	$60	$60	$60	$60	$60	$60
Training	$193.24	$200	$0	$0	$0	$0	$0	$0	$0	$0	$0
Administration/Billing	$91.96	$5	$5	$5	$5	$5	$5	$5	$5	$5	$5
Total	$2,266.21										
Regime 2d: Check yearly, resultant pumpout frequency on average every 10 years											
Septic Tank Pumping	$399.78	$0	$0	$0	$0	$0	$0	$0	$0	$0	$255
Inspection (including travel)	$1,106.42	$63	$60	$60	$60	$60	$60	$60	$60	$60	$60
Training	$193.24	$200	$0	$0	$0	$0	$0	$0	$0	$0	$0
Administration/Billing	$91.96	$5	$5	$5	$5	$5	$5	$5	$5	$5	$5
Total	$1,791.40										

Table 7-1
Example of Cost-Effectiveness Analysis (or Life-Cycle Cost Analysis of the Operation and Maintenance Stage) for Three Different Maintenance/Inspection Regimes (Cont.)

Operation and Maintenance	NPV	Year									
		1	2	3	4	5	6	7	8	9	10
Regime 3a: Install riser, check yearly, resultant pumpout frequency on average every 5 years											
Septic Tank Pumping	$874.59	$0	$0	$0	$0	$255	$0	$0	$0	$0	$255
Purchase and Installation of Riser	$483.09	$500	$0	$0	$0	$0	$0	$0	$0	$0	$0
Inspection (including travel)	$554.66	$33	$30	$30	$30	$30	$30	$30	$30	$30	$30
Training	$193.24	$200	$0	$0	$0	$0	$0	$0	$0	$0	$0
Administration/Billing	$91.96	$5	$5	$5	$5	$5	$5	$5	$5	$5	$5
Total	$2,197.54										
Regime 3b: Install riser, check yearly, resultant pumpout frequency on average every 10 years											
Septic Tank Pumping	$399.78	$0	$0	$0	$0	$0	$0	$0	$0	$0	$255
Purchase and Installation of Riser	$483.09	$500	$0	$0	$0	$0	$0	$0	$0	$0	$0
Inspection (including travel)	$554.66	$33	$30	$30	$30	$30	$30	$30	$30	$30	$30
Training	$193.24	$200	$0	$0	$0	$0	$0	$0	$0	$0	$0
Administration/Billing	$91.96	$5	$5	$5	$5	$5	$5	$5	$5	$5	$5
Total	$1,722.73										

Table 7-2
Summary Comparing the Life-Cycle Cost of Different Maintenance Regimes

Maintenance Regime	Action(s) Taken in This Regime	Predicted Pumpout Frequency	Sensitivity Analysis	
			NPV Over 30 Years for $255 Pumpout	NPV Over 30 Years for $300 Pumpout
Regime 1	Pumpout automatically every 2 years	N/A	$2,349.84	$2,756.55
Regime 2a	Check sludge level yearly	Every 3 years	$2,901.48	$3,167.93
Regime 2b	Check sludge level yearly	Every 4 years	$2,460.46	$2,649.07
Regime 2c	Check sludge level yearly	Every 5 years	$2,266.21	$2,420.55
Regime 2d	Check sludge level yearly	Every 10 years	$1,791.40	$1,861.95
Regime 3a	Install riser, check sludge level yearly	Every 5 years	$2,197.54	$2,351.88
Regime 3b	Install riser, check sludge level yearly	Every 10 years	$1,722.73	$1,793.28

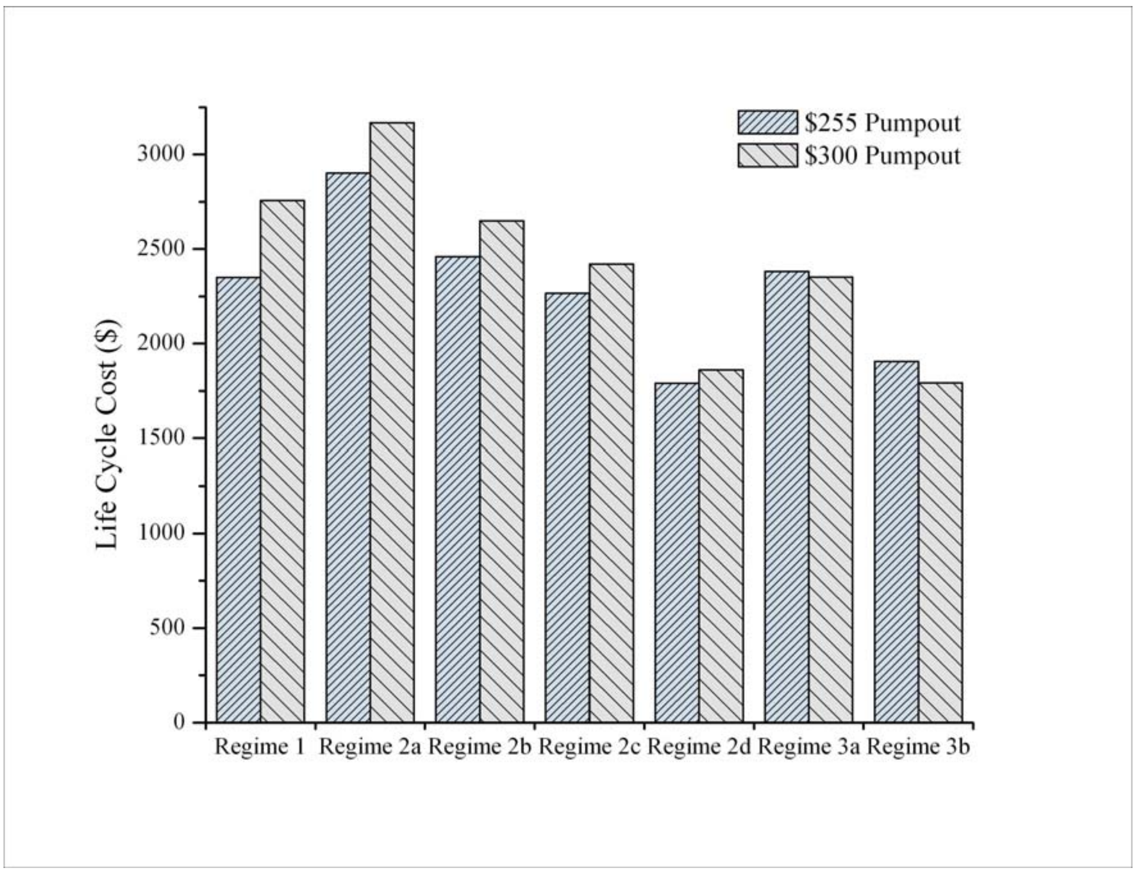


Figure 7-2
Graphical Presentation of How Different Maintenance Regimes Are Likely to Affect the Life-Cycle Cost of an Onsite System Over 30 Years

Some other applications where life-cycle costing is likely to give insight to decisions include:

- Building in redundancy (extra capacity) that will mean higher capital costs but potentially reduced risk of failure
- Reducing household water use (and therefore hydraulic load)
- Upgrading a system versus keeping the status quo
- Putting in a UV lamp to disinfect the effluent, which results in a relatively low capital cost, but operating costs (for electricity and bulb replacement) that may be significant

Jerry called Scott to tell him about the new nitrate regulations Valerie was working on, and that some preliminary maps of where they would apply included the new subdivision. “Any idea when they’ll take effect?” asked Scott.

“She’s talking about this legislative session,” replied Jerry. “So it could be soon. On the other hand, who knows how long it might drag out? Rule changes have taken ten or twenty years in some states.”

“How costly would this be?” asked Scott. He was wondering whether the extra cost would be enough that he would want to accelerate planning and construction to get systems in before the new regulations took effect. Scott had not thought through how much more costly they would need to be for him to want to accelerate construction, which was already on a tight but achievable schedule. He just wanted some numbers to start mulling over.

“It’s going to hit both the cost of the installed system and the rates. Any system that removes nitrogen is going to have moving parts on it, so we’ll be out inspecting it two to four times a year. I’d have to sit down and figure it out.” They agreed on a contract amendment for Jerry’s work, and Jerry tackled the lifecycle costs. Scott needed the construction costs to figure out how they affected the costs of the houses, and Jerry needed the O&M costs to figure out a rate structure.

He began by figuring out average construction costs for the last 20 conventional gravity systems he had constructed and the last 20 systems with sand filters. Then he figured in the average cost of each operations and maintenance task for each system, with the frequency that each O&M task is performed (Tables 7-3 and 7-4). With these data, he constructed a 30-year table showing how much in nominal dollars would be spent on O&M each year. Then, parallel to the first column, he made another column showing the net present value of each year’s O&M spending, using a 3.5% real discount rate. Adding together the results, he found that the conventional system cost around $5,000 over a 30-year lifecycle, and the sand filter system cost around $20,000.

“Boy, I wonder how much a denitrifying system is going to cost, then,” he said to himself. He had not installed a denitrifying system, but he made some calls and looked at some plans. Using the same type of tables, Jerry calculated that the denitrifying system would have a net present cost of around $25,000. The O&M was fairly similar to the sand filter system, so most of the difference between the denitrifying system and the sand filter was the initial cost.

Jerry realized that he had not included electricity costs in these calculations, but decided not to worry about it. After all, the homeowner paid the electrical bills… Jerry picked up the phone to give the news to Scott.

(Continued on next page)

Table 7-3
Life-Cycle Cost for a Conventional Gravity System

Capital Costs	
Cost of septic tank w/ gravity distribution	$2,950

O&M Schedule	Cost
Inspection (every 10 years)	$236
Pumpout septic (every 4 years)	$383

Constants	
Project lifetime (years)	30
Real discount rate	0.035

Life cycle cost	
Installation cost	$2,950
Net present O&M costs, 30 years	$1,974
Total life cycle cost	**$4,925**

O&M Costs Year	**Cost**	**Present Value**
1		$0
2		$0
3		$0
4	$383	$334
5		$0
6		$0
7		$0
8	$383	$291
9		$0
10	$236	$167
11		$0
12	$383	$253
13		$0
14		$0
15		$0
16	$383	$221
17		$0
18		$0
19		$0
20	$619	$311
21		$0
22		$0
23		$0
24	$383	$168
25		$0
26		$0
27		$0
28	$383	$146
29		$0
30	$236	$84
TOTAL		**$1,974**

Table 7-4
Life-Cycle Cost for a Sand Filter System

Capital Costs	
Cost of septic tank w/ gravity distribution w/ sand filter pretreatment	$8,596

O&M Schedule	Cost
Pump replacement (incl. $100 labor), every 8 years	$454
Sand filter replacement (every 20 years)	$428
Inspection (twice a year)	$236
Pumpout septic (every 4 years)	$383

Constants	
Project lifetime	30
Real discount rate	0.035

Life cycle cost	
Installation cost	$8,596
Net present O&M costs, 30 years	$11,293
Total life cycle cost	**$19,889**

O&M Costs Year	**Cost**	**Present Value**
1	$471	$455
2	$471	$440
3	$471	$425
4	$854	$744
5	$471	$397
6	$471	$383
7	$471	$370
8	$1,308	$993
9	$471	$346
10	$471	$334
11	$471	$323
12	$854	$565
13	$471	$301
14	$471	$291
15	$471	$281
16	$1,308	$754
17	$471	$263
18	$471	$254
19	$471	$245
20	$1,282	$644
21	$471	$229
22	$471	$221
23	$471	$214
24	$1,308	$573
25	$471	$199
26	$471	$193
27	$471	$186
28	$854	$326
29	$471	$174
30	$471	$168
TOTAL		**$11,293**

Case Study continues on Page 7-18…

7.3 Activity-Based Costing (ABC)[20]

The activity-based costing tool is useful to anyone conducting life-cycle costing. Activity-based costing is similar to the second step in life-cycle costing, where a cost breakdown structure (CBS) is developed in order to create a life-cycle model. A cost breakdown structure is a form of activity-based costing, where costs are allocated to appropriate products or services. The use of even simple ABC tools can raise awareness of the true costs of certain activities. Better cost accounting means that managers gain knowledge of financial impacts of different choices and will be able to direct resources more strategically and efficiently.

The ABC costing method requires linking costs directly with the activity that generates the cost. This accounting method contrasts with usual methods of accounting in which costs are lumped by department or other grouping and overhead costs are often allocated arbitrarily. ABC is a powerful tool that can show accurate and complete costs for a particular product or service area. The basic premise of ABC is that a cost object consumes activities, activities consume resources, and resource consumption drives costs. The more activities needed to produce a cost object, the higher the cost is likely to be. Understanding this relationship is critical to successfully managing indirect (or overhead) costs in an organization.

Using the ABC tool involves determining what resources (time, labor, and other resources) are needed to complete an activity in support of a particular goal (usually a product or a service). Some of the changes that using this tool might induce include examining real costs of using scarce resources for capital expenditure and determining labor-time spent on a specific activity.

7.4 How to Do Activity-Based Costing

Activity-based costing has four simple steps. Like LCC, it starts with clear planning. The key is to disaggregate costs and re-aggregate them on the basis of particular activities.

7.4.1 Planning and Choice of Cost Object(s)

As with LCC, it is important to first consider desired outcomes. What questions need to be answered? Knowing this will help guide the level of detail required in the analysis and will impact the kinds of cost objects chosen. A cost object is the product or service for which the true cost must be known. Is the cost object a service for a specific customer, or for a set of customers? Is the cost object related to single systems or a group of systems? Is the cost object related to a particular type of repair?

[20] This section draws heavily from Koplow (1998).

7.4.2 Cost Measurement

ABC relies upon accurate cost information. These include but are not limited to purchases, payments, and labor costs. It is important divide labor costs based on the activity on which the labor was spent. Timesheets may be used to capture how much time employees spend on different tasks.

7.4.3 Cost Allocation

Cost allocation is done by distributing costs to functional areas called “activity cost pools.” The first step is to define the activity cost pools, and the second is to decide how costs should be assigned to different pools.

Some examples of defined pools for wastewater treatment are treatment, transmission, collection, dispersal, billing, customer service, accounting and finance, and administration. Activity cost pools for an onsite wastewater system inspection include pre-inspection data review, travel to and from the site, site inspection, sampling, analyzing samples, and post-inspection write-up.

Cost assignment may be thought of in terms of the driver of a particular cost. For example, collection pipes for a centralized treatment system might be disaggregated into areas of customers according to location. It is then possible to differentiate between the costs of collection lines for customers close to the treatment plants and those further away. When true costs are known, it may become clear which areas and customers are more cost-effectively served by a decentralized service.

7.4.4 Determining “True” Costs of Chosen Cost Objects

A summary is made of the direct and indirect costs associated with the cost object. Direct costs include materials, labor, energy, and capital that are directly attributable to creating or servicing a particular cost object. Indirect costs include telephone, vehicles, administration, laboratory equipment purchase and upkeep, and computer purchase and upkeep.

If this inspection were costed only by considering the inspector’s time the cost might be $30, but many costs related to the activity would not be accounted for (Table 7-5). Activity-based costing reveals the true activity cost. Knowing the true cost of an activity, or a good approximation of the true cost, is essential for making decisions between operation and maintenance strategies for onsite systems over the long term. The following example of the installation of a replacement septic tank due to a failed leaking tank shows the many direct and indirect costs related to this activity (Table 7-6).

Table 7-5
Cost Object: Inspection of Tank With No "As-Built" Drawing Available

Activities	Resources Required	Costing Basis	Cost Allocation		
			Units	Rate	Cost
Pre-inspection preparation—try to obtain "as-built" drawing from County Health Department	Clerical time—phone contact to County	Labor time	0.3h	$25/h	$7.50
	Clerical time—phone contact to homeowner to schedule inspection	Labor time plus telephone time	0.2h	$25/h	$5.00
Travel to and from the site	Vehicle gas, repairs, insurance	Average charge per mile traveled	40 miles	$0.37	$14.80
	Inspector travel time	Labor time	0.8h	$30/h	$24.00
Since no "as-built" available, dig to find tank and locate all components	Digging	Labor time	3h	$40/h	$120.00
	Use of electronic locator	Pro-rated share of total cost of equipment used	0.5h	$0.50/h	$0.25
	Field drawing of location of components	Labor time	0.3h	$30/h	$9.00
Inspection—includes examining tank, distribution box, all lines, and leachfield	Inspection time	Labor time	1h	$30/h	$30.00
Draw up "as-built" drawing and pass on to County Health Dept. and homeowner	Use drawing made in field to create "as-built" form required by county	Labor time	1h	$30/h	$30.00
	Make copies and submit to county and homeowner	Labor time	1h	$25/h	$25.00
Post-inspection—write report	Write out report based on notes made in the field	Labor time	0.4h	$30/h	$12.00
	Entry to information system	Labor time	0.2h	$25/h	$5.00
Total					*$282.55*

Table 7-6
Cost Object: Installation of a Replacement Tank in Place of a Leaking Tank

Activities	Resources Required	Costing Basis	Cost Allocation		
			Units	**Rate**	**Cost**
Pre-installation preparation	Clerical time—phone contact to schedule installation	Labor time	0.3h	$25/h	$7.50
	Organize materials, equipment, etc.	Labor time	1h	$25/h	$25.00
Travel to and from the site	Vehicle gas, repairs, insurance	Average charge per mile traveled	40 miles	$0.37	$14.80
	Installer travel time	Labor time	0.8h	$30/h	$24.00
Pumpout existing tank	Use of equipment: truck with pump	Pro-rated share of total cost of equipment used	2h	$35/h	$70.00
	Fee to dump sludge at WWTP	Direct cost	—	$180	$180.00
	Pumper time	Labor time	2h	$30/h	$60.00
	Truck gas, repairs, insurance	Average charge per mile	30 miles	$0.50	$15.00
	Pumper travel time	Labor time	1h	$30/h	$30.00
Crush old tank (to then backfill with material from new hole)	Machine time	Pro-rated share of total cost of equipment used, maintenance, diesel, replacement	1h	$35/h	$35.00
	Installer time	Labor time	1h	$30/h	$30.00
Dig hole for new tank (assuming able to use same distribution box) and install new tank	Machine time	Labor time	8h	$35/h	$280.00
	Installer time	Labor time	8h	$30/h	$240.00
	Tank	Direct cost	—	$600	$600.00

Table 7-6
Cost Object: Installation of a Replacement Tank in Place of a Leaking Tank (Cont.)

Activities	Resources Required	Costing Basis	Cost Allocation		
			Units	Rate	Cost
Hook up tank to house and distribution box	Installer time	Labor time	8h	$30/h	$240.00
	Pipe and couplings required	Direct cost	—	$50	$50.00
Install risers and effluent filter	Installer time (cut fiberglass to size and install)	Labor time	1h	$30/h	$30.00
	Risers material costs (includes glue, fiberglass riser and fiberglass lid) for two risers, inlet and outlet	Direct costs	—	$300	$300.00
	Effluent filter	Direct cost	—	$50	$50.00
Submit permit to County Health Department	Clerical time	Labor time	1h	$25/h	$25.00
Update and submit new “as-built”	Installer time	Labor time	1h	$30/h	$30.00
	Clerical time	Labor time	0.3h	$25/h	$7.50
Total					*$2,343.80*

The next day, Jerry looked again at his life-cycle cost calculations with mixed feelings. He felt satisfied, almost smug, to be able to look 30 years into the future and plot out costs. On the other hand, he was uneasy. What if he was wrong? Was he missing something? Where could he be wrong? Where would being wrong hurt him the most?

That last question seemed easy to answer: being wrong about the cost of inspections could hurt him a lot, at least for the sand filter and the denitrifying system. Two inspections a year for thirty years comprised the bulk of their O&M costs. He decided to investigate the cost of inspections more closely.

On a fee basis, The Zone performed inspections for systems that it was not responsible for. Home buyers and people having trouble with their systems were the most frequent customers. To get the cost of inspections for the life-cycle costing, Jerry had taken the average invoice for the last 20 inspections they had done.

(Continued on next page)

He figured that this approach would err on the high side, since on someone else's system, it was more likely that they would have to poke around or dig to find the septic tank and leachfield, and the driving time was longer to systems outside their normal service area. In addition, the inspections on The Zone's systems were usually routine, and about one-third of the outside inspections were of systems in trouble, which took more time. If he had correctly invoiced people, the average cost of those 20 inspections would be higher than the average cost of inspections of their own systems.

Jerry's staff performed most of the inspections these days, but Jerry made a point of taking the next outside inspection himself, to remind himself of everything involved. Afterwards, he made up a list of all the steps and circulated it among his staff for comment. The secretary added quite a few steps he had not thought of, like the initial call with the homeowner to schedule the inspection and calls and reports to the health department. The end result looked like Table 7-5. When Jerry went back over the 20 invoices he had used in his calculations, he filled in the average costs found in Table 7-5. However, he found that the clients had not been billed for the secretarial tasks, so those he estimated with the help of the secretary. He was unhappy with the result: the average invoice had been $236 for a service that cost them an average of $283 to perform. Jerry decided to start tracking more costs by activity.

(Case Study continues on Page 7-29…)

7.5 Risk-Cost Modeling Tool

The risk-cost tool aids in understanding the probability of a failure and the financial implications of that failure. It is based on the conceptual definition "risk = probability × consequence", where consequence is measured and reported as the severity of impact of an event. In risk-cost analysis, consequence is measured in dollars, adding a financial element to inform investment decisions with regard to reliability. It may be used to prioritize which decentralized systems need urgent attention, and to determine a cost-effective balance between reactive and proactive maintenance. This tool is only useful for assessing risks to which costs or cost estimates may be assigned. Non-monetary risks require other methods of treatment (see discussion in Sections 6.2 and 6.3) and may be used to set performance standards (for example, higher requirements for environmentally sensitive areas) and direct investment (for example, more stringent monitoring and inspection in environmentally sensitive areas).

The risk-cost modeling tool may be used in many different ways. Two possibilities are explained in this handbook. Risk-Cost Method A enables sorting of a set of assets from highest risk-cost to lowest risk-cost, and focuses attention on those assets that have the highest risk-cost over a given time period. Based on actual costs calculated in this list, an assessment can be made of the cut-off point at which it is worth intervening with inspection, preventive maintenance, or replacement. In Risk-Cost Method B, rather than creating an actual list by calculating risk-cost, the tool is used in a broader approach that places assets into a matrix of failure probability versus consequence (cost) of failure. The matrix is used to determine which assets or groups of assets should be addressed first (those having both a high probability and consequence of failure).

Risk-Cost Method A: The risk-cost of an event is found by multiplying the dollar consequences of an event and the probability of that event occurring in a given time period. For this application, the dollar value of the consequences of a failure and the probability of that failure both should be estimated to an acceptable degree of accuracy depending on the application, potentially involving detailed modeling based on multiple parameters to determine the most accurate values possible.

The most common way of estimating failure probability over time is to use a reliability tool like the failure curve (discussed in Section 5.3).

Finding the cost of consequence involves estimating monetary costs and any environmental or social costs that are incurred by a failure. In the centralized field, asset management leaders are finding ways to value and incorporate non-monetary costs (Fane 2005). It will be necessary to develop appropriate ways to include these costs in the decentralized field. Inconvenience to homeowners, risk to homeowners' health, and potential for ecological impact are examples of the non-monetary costs that will need to be considered in using this tool.

For each individual asset, an estimated probability of failure over a certain time period multiplied by the cost of the consequence of that failure yields the "risk-cost" for that asset over the specified time period.

Risk-Cost Method B: A more useful application of risk-cost is to map probability of failure and dollar consequences in a matrix to enable differentiation of different types of assets (Table 7-7).

The centralized wastewater sector is moving away from investing effort in detailed reliability and cost modeling towards categorizing probability and consequence (Martin 2004). This movement is occurring for two reasons. Multiplying probability and cost to get a single value hides important information. For example, a high risk-cost could be the product of a low probability and a high cost, or vice versa. The nature of the risk and the cost are important elements in decision-making, and therefore are useful to retain as separate elements. Additionally, a high degree of uncertainty is inherent in many parameters used in risk-cost models. Unpredictable external factors often undermined the accuracy of predicted results, and more useful information for decision-making could be obtained through the categorization process.

One application of Risk-Cost Method B is shown in Table 7-7. Even if detailed reliability data or costing information is not available, the matrix makes it possible to see which assets are the most strategic. In Table 7-7, it would make sense to focus attention first on asset groups D and E.

The risk-cost tool can be used to examine existing situations, hypothetical scenarios, and different types of possible failures and associated costs. Approximating costs for consequences of failure at onsite systems installed in different situations could shed light on which systems or aspects should be prioritized in terms of maintenance and improving reliability.

Table 7-7
Risk-Cost Matrix

Consequence of Failure ($) \ Probability	1 (low)	2	3	4	5 (high)
1 (low)	Asset group C	Asset group G			
2		Asset group B		Asset group H	
3	Asset group A				
4		Asset group F			
5 (high)				Asset group E	Asset group D

7.5.1 How Centralized Utilities Benefit From Using Risk-Cost: Seattle Public Utilities

Seattle Public Utilities (SPU) developed a risk-cost model to determine cost-effective maintenance regimes with the right mix of proactive and reactive maintenance. They use Risk-Cost Method A to determine which pipe segments are worth inspecting. This section includes information about how SPU created the risk-cost model and a figure that generally explains their spreadsheet-based risk-cost model.

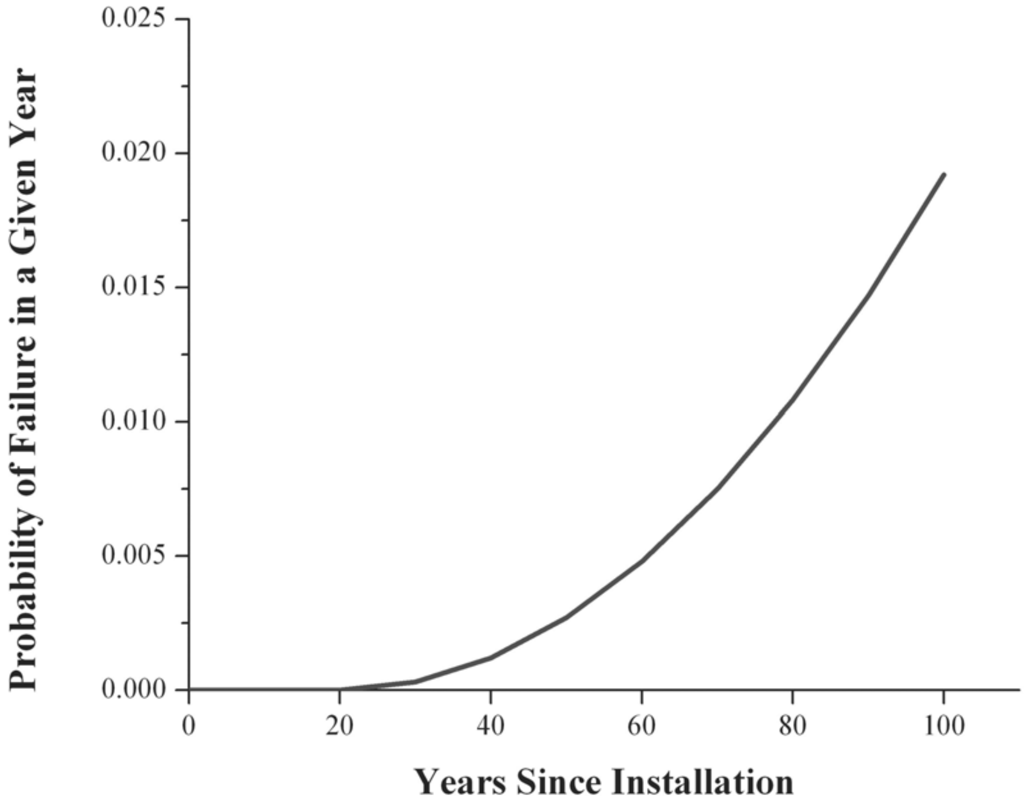
Calculating Probability of Failure

SPU currently uses Weibull curves to describe failures of a set of pipe assets (different curves depending on the material; eight curves for concrete, clay, brick, corrugated metal, several kinds of plastic, and metal). They currently use generic Weibull curves supplied by another water utility. Their observed probability of failure is 10 times lower than predicted by these curves. Eventually they will adjust the curves to match their assets, but for now they can arrange assets in a hierarchy and know where to concentrate. For the risk-cost model, a percent probability that the asset will fail over a given time period (for example, between year 90 and year 95 of the asset's life) is calculated from the Weibull curve. SPU

Using the Concept of Risk-Cost to Inform Decisions on Collection System Options

In Warren, Vermont, a large 30,000 gpd cluster system was built with 100% redundancy beyond design flows. Each 5,000-gpd bed is designed to be in service every other year. One of the original beds built in 1997 recently failed because the effluent filter in the septic tank could not keep up with the surge of raw sewage pumped from a mix of gravity pipes and grinder pumps. The force of movement of the water allowed solids to reach and clog the field, causing effluent to surface. The risk-cost tool would help to consider consequences of different types of failures based on collection system options, and would inform actions to minimize both risk and cost.

determined that the most influential factors in the probability of failure were age and location of the pipe. Age was important due to material degradation, while location allows the inclusion of factors such as being downstream of a chemical producer, being on a steep slope (the area is hilly and soil-creep down the hill leads to the separation of joints), and being in a liquefaction zone in the determination of the probability of failure. Various multipliers are used to account for the effects of these factors. Data from previous failures (a representative sample of 40 to 50 repairs from the last five years) were used to roughly calibrate the probability multipliers.



(Martin 2004)

Figure 7-3
Example of the Weibull-Based Failure Distribution Graph Used for Vitrified Clay Pipe

Calculating the Cost of the Consequence of Failure

The cost of the consequence of failure is a sum of the repair costs and any environmental or social costs incurred by the failure or during the repair process. An example of a social cost of repairing a failed pipe is where the utility digs up a main street to repair a pipe, causing traffic delays. The cost of repair is dependent on repair type, pipe age, failure mode, pipe depth, pipe diameter, and pipe location. A set of multipliers was also developed to account for these factors. The multipliers were determined through iterative trialing of different multipliers until results were roughly consistent with data from 40 to 50 past failures and their costs of repair. From the equation with appropriate multipliers, a cost of repair is estimated:

$$Cost\ of\ repair = f(d) \times M$$

Where d is depth
M is a multiplier based on location

SPU uses the risk-cost of a pipe as a guide to determine whether it is worth investing in proactive inspection or maintenance. The rationale is as follows: if the total risk-cost of pipe segment failure costs more than it would cost to inspect that segment using closed circuit television (CCTV, where video cameras are pulled through pipes to record their condition), then it is worth using CCTV. Pipe segments for which the risk-cost is lower than the cost of using CCTV are allowed to run to failure without inspection and are dealt with reactively. Pipes with high risk-cost are generally located under or near major infrastructure, such as freeways or hospitals. Low risk-cost pipes are typically located toward the end of distribution systems in the suburbs.

Figure 7-4 shows the structure of the risk-cost model as it looks laid out in a spreadsheet. All the information relating to a single asset is contained in a single row. The last column gives the total risk-cost for each asset. The figure shows the structure of information needed to calculate both probability and cost of consequence. The details of the kinds of information included in each set are shown in Table 7-8.

Activity-based costs of pipe segment point failure based on depth of the pipe

Dollar value of various other consequences of pipe failure: location-specific, environmental, and social costs

Total risk-cost of the pipe segment

Seattle Public Utilities Sewer Pipe Risk Model (© City of Seattle 2004)

Multiplied — Additive Cost

Pipe Segment GIS Data						Generic Cost of Pipe Segment Failure Repair Based on Depth														Consequence of Point Failure for Pipe Segment — Consequence of Failure Based on Location, Service Area Size, etc.									Probability of Point Failure for Pipe Segment — Probability of Failure Based on Location			Probability of Failure Based on Age & Material				TOTAL RISK-COST
Pipe ID	Year of Installation	Diameter	Material	Avg. Depth	Length	Repair Time	Crew	Total Crew Hours	Total Crew Cost	Equipment	Total Equipment Hours	Total Equipment Cost	Shoring	Total Shoring Cost	Dewatering	Total Dewatering Cost	Bypass Pumping	Total Bypass Pumping Cost	Generic Total Cost of Pipe Segment Point Failure Repair	Critical Pipe Consequence Designation	Critical Consequence Designation Multiplier	Critical Pipe Consequence Designation Associated Costs	Regulatory Non-Compliance Potential Additive	Environmental Damage Potential Additive	Social Disruption Potential additive	Public and Private Property Damage Potential Additive	Unfavorable Publicity Potential Additive	Consequence of Point Failure for Pipe Segment Total Cost	Critical Pipe Probability Designation	Critical Pipe Probability Designation Multiplier	Probability of Point Failure for Pipe Segment Total Cost	Age	Age<20 years?	Material Code	Probability of Point Failure (Based on Age and Material Before Next CCTV Inspection	Total Risk-Cost of Point Failure (Consequence of Failure X Probability of Failure) Before Next CCTV Inspection
No.	Year	In.	Type	Ft.	Ft.	Hrs	No.	Hrs	$	No.	Hrs	$	No.	$	No.	$	No.	$	$	No.	No.	$	Low=$0 Med=$20k High=$100k	Low=$0 Med=$10k High=$30k	Low=$0 Med=$10k High=$30k	Low=$0 Med=$20k High=$100k	Low=$0 Med=$20k High=$100k	$	No.	No.	$	Yrs	Logical (Yes=0 No=1)	1-9[1]	%[2]	$
013-234 013-295	1908	42	OTH	15.6	356	20	6	120	$9,000	3	60	$7,500	12	$600	8	$1,600	3	$900	$19,600	Diameter >= 36 inches	4	$58,800	$ –	$ –	$ –	$ –	$ –	$58,800	Potential Liquefaction Area	2	$19,600	96	1	6	0.1692	$16,581.60
042-224 042-320	1903	36	CON	48.1	7	32	7	224	$16,800	4	128	$16,000	20	$1,000	12	$2,400	3	$900	$37,100	Diameter >= 36 inches	4	$111,300	$ –	$ –	$ –	$ –	$ –	$111,300	Potential Slide Area	1.5	$18,550	101	1	2	0.0984	$16,427.89
034-135 034-134	1903	8	REL	10.75	141	14	5	70	$5,250	2	28	$3,500	8	$400	6	$1,200	0	–	$10,350	Arterial or Concrete Street	1.5	$5,175	$ –	$ –	$ –	$ –	$ –	$5,175	Potential Slide Area	1.5	$5,175	101	1	3	0.7873	$16,297.11
045-086 045-087	1906	18	CIP	22	40	32	7	224	$16,800	4	128	$16,000	20	$1,000	12	$2,400	1	$300	$36,500	Arterial or Concrete Street	1.5	$18,250	$ –	$ –	$ –	$ –	$ –	$18,250	Potential Liquefaction Area	2	$36,500	98	1	6	0.1782	$16,260.75

GIS data for each pipe segment

Total cost of repair if this pipe segment fails

Probability of pipe failure in the given time period based on either location or pipe age/material

[1] 1=VC, 2=CON, 3=REL, 4=PVC, 5=AC, 6=OTH, 7=DIP, 8=CIP, 9=CMP
[2] % based on Weibull Curve and 5 year CCTV return cycle

Figure 7-4
SPU's Risk-Cost Model as Set Up in Microsoft Excel™

Table 7-8
Detailed Risk-Cost Model Information

Information Set and Output	Detailed Information	
GIS data for each pipe segment	• Pipe identification number • Year of installation • Pipe diameter	• Material • Average depth • Average length
Activity-based costs of pipe segment point failure Output: Generic total cost of pipe segment point failure repair	• Repair time • Crew number • Total crew hours • Total crew cost • Equipment number • Equipment hours • Equipment cost	• Shoring number • Shoring cost • Dewatering number • Dewatering cost • Bypass pumping number • Bypass pumping cost
Dollar value of other consequences Output: Consequence of Point Failure for Pipe Segment Total Cost	• Pipe consequence designation number • Critical pipe consequence designation multiplier • Critical pipe consequence designation associated costs • Regulatory non-compliance potential additive	• Environmental damage potential additive • Social disruption potential additive • Public and private property damage potential additive • Unfavorable publicity potential additive
Probability of point failure for pipe segment	• Critical pipe probability designation • Critical pipe probability designation multiplier • Probability of point failure for pipe segment total cost	• Age • Age < 20 years? • Material code • Probability of point failure (based on age and material) before next CCTV inspection

7.5.2 Risk-Cost Decentralized Systems: Groundwater Mounding Application

Researchers at the Colorado School of Mines applied a version of risk-cost to determine appropriate levels of effort for hydrogeologic analysis under cluster and high-density soil absorption systems (Poeter *et al.* 2005). Groundwater mounding is a localized rise in groundwater levels where effluent is infiltrated. Its consequences can include surfacing (including breakout on side slopes) of untreated effluent or interference with subsurface treatment processes. Ways to determine the potential for groundwater mounding at a given site range from simple manual calculations to sophisticated computer modeling, based on field investigations that can range from simple to elaborate.

In the method, the probability of mounding is subjectively rated using Table 7-9. Weights may be assigned on the basis of site-specific considerations. For example, hydraulic conductivity of bedrock ("Bedrock character" in the table) is less important if it is further below the surface.

The consequence of failure due to excessive mounding or breakout is also subjectively rated using Table 7-10. The probability of mounding (mounding potential) and consequences of failure are then plotted together in Table 7-11. Based on the combined total of the mounding potential and the consequences, a score from 0 to 5 is assigned to the site.

For each of the scores obtained using this method, a different level of effort is prescribed for the amount of data gathered in the field and how the data are processed. For example, sites assigned a score of 1 would have depth to water table and fluctuations in depth estimated from local well data, while sites assigned a 5 would have long-term water level monitoring at multiple sites, correlated with a geophysical analysis. Similarly, sites assigned a score of 1 would be modeled using manual calculations applying Darcy's law, whereas sites scored 5 would need sophisticated numerical modeling, possibly involving hundreds of hours of work and uncertainty evaluation using stochastic sampling.

Table 7-9
Quantification of Subjective Evaluation of Mounding/Breakout Potential

Parameter	Low 1	High 10	Value	Weight 0-1 (WT)	Site Rating (Value × WT)
Loading rate	Low (<1 cm/day)	High (>6 cm/day)			
Soil type	Sands, clay-loams	Fine-sand, heavy-clay			
Soil sorting	Poor	Well			
Soil structure	Granular/ blocky	Platy/prismatic/ massive			
Soil heterogeneity	Uniform	Variable			
Drainage	Moderate to well	Poor			
Depth to water table/ low K layer	Large	Small			
Proximity to slopes	Far	Near			
Bedrock character	Homogenous, high K	Heterogeneous, low K			
Characteristic curve for K_{unsat}	Flat	Steep			
Horizontal hydraulic conductivity	High	Low			
Proximity to wetlands	Far	Near			
Prone to intense storms	No	Yes			
				WTs sum = 1.0	Sum of Weighted Ratings

(Poeter *et al.* 2005)

Table 7-10
Consequence of Failure

Condition	Mild 1	Serious 5	Site Rating
Alternative infiltration area locations	Numerous	None	
Timing relative to full construction	Early	Late	
Proximity to shallow water supply	Far	Close	
Proximity to surface water and sensitive habitats	Far	Close	
Local population density	Low	High	
		AVERAGE	

(Poeter *et al.* 2005)

Table 7-11
Strategy Level for Each Consequence of Failure

Mounding Potential	Consequence of Failure				
	1	**2**	**3**	**4**	**5**
1	0	0	1	1	2
2	0	1	1	2	2
3	1	1	2	2	3
4	1	2	2	3	3
5	2	2	3	3	4
6	2	3	3	4	5
7	3	3	4	5	5
8	3	4	5	5	5
9	4	5	5	5	5
10	5	5	5	5	5

(Poeter *et al.* 2005)

Jerry was visiting Valerie again, discussing the cluster system alternative for the subdivision. He wanted to make sure that she was on board for the site assessment he intended to perform. “Funny you should bring that up,” she commented. “We have our state regulations on what sort of site assessment to conduct, but they are pretty vague. That’s fine, I guess, as long as someone who understands site assessments is administering the rules. We have a feeling for which sites are going to be problematic and therefore require more detailed tests. Still, I’d like to leave something more formalized in place before the end of my career—you never know who is going to replace you, right?”

She pressed the print button on her computer and handed Jerry the pages. “I’ve been reading about a new method for deciding how much effort to put into mounding analysis. It’s based on both physical characteristics of the site and more social and economic and even plain practical questions, like how far along in the construction process you are. Would you humor me and walk through this process with the site you’ve proposed?” Jerry assented.

They spread out the “risk” table (Table 7-12) before them, and talked about how to fill it in. “The loading rate we can vary through the design; let’s set that at about 3 cm/day for now and see where that gets us,” Jerry said. “It’s pretty sandy, even in the uplands there. Give that a 3.” They continued filling in the table. First they distributed weights evenly among criteria. They decided to downgrade bedrock character, since bedrock was deep enough to make little difference. Loading rate was scored higher than intense storms. Since the site was near a slope, they upped the weight for horizontal conductivity so that the sum of the weights was 1.0.

Table 7-12
Subjective Evaluation of Mounding/Breakout Potential for a Subdivision Site

Parameter	Low 1	High 10	Value	Weight 0-1 (WT)	Site Rating (Value × WT)
Loading rate	Low (<1 cm/day)	High (>6 cm/day)	5	0.1	0.5
Soil type	Sands, clay-loams	Fine-sand, heavy-clay	3	0.0769	0.2307
Soil sorting	Poor	Well	7	0.0769	0.5383
Soil structure	Granular/blocky	Platy/prismatic/massive	3	0.0769	0.2307
Soil heterogeneity	Uniform	Variable	5	0.0769	0.3845
Drainage	Moderate to well	Poor	3	0.0769	0.2307
Depth to water table/ low K layer	Large	Small	4	0.0769	0.3076
Proximity to slopes	Far	Near	8	0.0769	0.6152
Bedrock character	Homogenous, high K	Heterogeneous, low K	8	0.05	0.4
Characteristic curve for K_{unsat}	Flat	Steep	5	0.0769	0.3845
Horizontal hydraulic conductivity	High	Low	4	0.0769	0.3076
Proximity to wetlands	Far	Near	1	0.0769	0.0769
Prone to intense storms	No	Yes	10	0.06	0.6
Sum				1	4.8

(Adapted from Poeter *et al*. 2005)

They turned to the "cost" table (Table 7-13). "Alternative infiltration area locations?" asked Valerie.

"Numerous," replied Jerry, mimicking the table's language. "We have 35 acres to work with, and maybe half of it seems like it might be suitable. And we're sure early relative to full construction. Shallow water supply? I expect all the houses will have drilled wells, so that's a 1."

"I don't know what 'far' and 'close' mean exactly for the proximity to surface water," said Valerie, "but it ain't Arizona. That creek is 100 yards away, so there's some potential for breakout there. Give it a 4. But the population density is pretty low, so give that a 2."

Table 7-13
Consequence of Failure for a Subdivision Site

Condition	Mild 1	Serious 5	Site Rating
Alternative infiltration area locations	Numerous	None	1
Timing relative to full construction	Early	Late	1
Proximity to shallow water supply	Far	Close	1
Proximity to surface water and sensitive habitats	Far	Close	4
Local population density	Low	High	2
		AVERAGE	1.8

(Adapted from Poeter *et al.* 2005)

Reading off the "Strategy Level" table, Valerie said, "Consequences of failure are about 2 and mounding potential is about 5: we're looking at strategy level 2. Which is…" She turned some pages to a chart. "Well, it includes a lot of things. Sieve analysis of soil sorting, a fair number of hand soil samples from test pits, monitor fluctuating water levels with piezometers, perc test for vertical conductivity and lab test for horizontal conductivity. Sound like what you had in mind?"

"A little more elaborate than I'd hoped," replied Jerry. "How about we just go with the state rules for now and leave developing this project until later?"

(Case Study concludes on Page 9-5…)

8 DATA NEEDS

Assessing reliability and costs requires data. The types of data needed for each tool have been discussed in conjunction with each tool. This chapter contains an overview of data types and where to find them, plus discussion of how to store and access the data, and what quality and types of data are needed.

8.1 Data Collection

A good deal of existing data are available for use in decentralized wastewater reliability assessment, and ongoing projects have the potential to make more data easily available. Assessing data quality is important to any use of data—the GIGO (garbage in, garbage out) rule applies to wastewater system analysis as much as anything else.

8.1.1 Types of Existing Data

Whether a particular set of data is useful for a given reliability study depends, in part, on whether they are locally or generally applicable and the extent to which they are compiled and analyzed (see Section 8.1.2).

Location-specific data are like the data that Jerry collects in the Zone example: data about performance of systems in a specific location, which may not be transferable to any other place. For example, data collected in the Holliston, Massachusetts study described in Section 5.4.1 include information about repair permits, which would allow calculations of failure rates for various types of systems. However, the failure mode is not consistently a part of the data set, and repair permits could be issued for many reasons: for example, the failure to pass a state inspection, reporting of a public nuisance (such as, sewage on the surface) by a neighbor, or a recommendation from a septage pumper to replace a corroded septic tank. While the data may be sufficient to accurately predict future failure rates in Holliston, or maybe even elsewhere in Massachusetts, there may not be any information in the data set that could be transferred to other states—the data include too many unknown factors.

Data can be applicable in a wide variety of places when there are fewer unknown factors. Components like pumps, for example, are manufactured in large numbers in standardized ways. Assuming they are installed according to the manufacturer's specifications, then performance could be expected to vary little from Massachusetts to Mississippi. In fact, a wastewater service provider reports that manufacturers of pumps and other electrical components have, when requested, given him data on number of hours or cycles the components were expected to last (Stonebridge 2004). The data, he says, have generally been in accordance with his own experience. For example, when pump contactors were burning out frequently, he asked the manufacturer how many on-off cycles they were rated for and learned that it was an "astronomical" number, far more than he expected the pumps to have gone through in systems of that age. That information helped him discover that the wrong type of float was used in those systems, causing very rapid on-off cycling.

If locally constructed system components are highly standardized in some way, then it may be possible to draw more general conclusions from data about their performance. For example, mound systems are constructed with a specified type of sand. Converse (1999) reports that the United States Department of Agriculture (USDA) classification "medium sand" was used for mound fill, but premature failure (presumably, surfacing of effluent) was found in types of sand that fell into the "medium sand" classification. He now recommends that "coarse sand with a minimum amount of fines" be used, and further specificity is provided by ranges for sieve analysis of the sand. Mound systems constructed according to standards like these may show a high enough degree of uniformity to enable generalization of performance results from one jurisdiction to another.[21]

The difference between generally applicable and location-specific data sets is more of a gradation than a sharp line. For example, a study of failure rates in northern Ohio (CT Consultants 2001) is described in Table 8-1 and classified as location specific. Jurisdictions outside Ohio may have different ways of describing the soils than Ohio uses, and they may not even permit systems to be constructed on the soils with severe limitations, or they may require pretreatment or some other measures. These jurisdictions would learn little directly applicable to forecasting failure rates for their systems from the Ohio study. On the other hand, the study results may be easily transferable to other counties in Ohio, and outside of Ohio the study results may be used to justify stricter requirements for systems constructed on soils with severe limitations—if the soil description can be matched with Ohio's system. Another possibility is that a controlled study may yield lessons about the effectiveness of certain measures in increasing system reliability, even if the failure rates for system types in the study area are not directly transferable to anywhere else. For example, Lindbo *et al.* (1998) followed up on a study of failure rates performed through statistical field sampling by Hoover *et al.* (1993) in North Carolina five years after a management entity had been put in place. Under improved management, the percentage of systems found to be failing in the same area dropped from around 30% to 1%; the lesson surely has implications far beyond North Carolina.

The extent to which data are compiled and the way in which they are analyzed (if at all) is also important in choosing data to use for a reliability study. Some data are simply *collected*; health department permit data often are found only in paper files. *Compiling* those data into an electronic database can be a large effort, costing tens of thousands of dollars. For a local reliability study, the expense of compilation may well be worth it—compilation both gives the basis for a meaningful, fact-based analysis of the state of local systems and produces a database that is useful for administering a subsequent management program. Finally, the data may come

[21] Whether they actually are constructed according to the standards may depend both on the existence of the standards and the education and motivation of the designers, installers, regulators. Converse (1999) credits the success rate of over 95% for mounds in Wisconsin to, in part, "a very strong educational program relating to siting, design, and construction."

already *analyzed,* and the results of the analysis may be used directly. For example, the performance data for pump contactors that was mentioned above was already analyzed to give expected hours or cycles of operation. Where these already analyzed data sets exist and can answer questions useful to a reliability study, they can greatly reduce the cost of the study.

Table 8-1
Examples of Types of Reliability Data Available

	Generally Applicable	Location Specific
Data Analyzed	NSF International's Standard 40 shows which pretreatment systems meet a specific set of performance criteria in a test center: http://www.nsf.org Manufacturers of pumps and other components have data on expected lifetimes, in hours or cycles Leverenz *et al.* (2002) contains probability distributions of performance in wastewater treatment components Anderson *et al.* (1998) report on extensive studies of pretreatment for nitrogen and phosphorus reduction. While they report the data in terms of means and ranges, instead of probability distributions, they do show which technologies consistently meet a set of performance standards.	CT Consultants (2001) studied rates of failure (defined as surfacing effluent) in decentralized wastewater treatment systems in seven counties in Ohio. For onsite systems, they found a significantly higher failure rate on soils with severe limitations for effluent dispersal than on soils with low to moderate limitations, and a slight inverse correlation between failure rate and depth to groundwater.
Data Compiled, Not Analyzed for Reliability	The La Pine Demonstration Project in Oregon has large amounts of performance data for pretreatment systems online that could be analyzed with reliability tools. http://www.deq.state.or.us/wq/lapinedata/SiteRptCriteria.asp	South Carolina has much of its permit data computerized in databases at county health departments, but the data have not been analyzed for reliability purposes, as far as the authors are aware.
Data Collected, Not Compiled	Many states require regular monitoring and reporting of effluent from pretreatment units. An official in one state, which may not be unique, admits that the reports are merely filed, without analysis of any kind.	Many local jurisdictions have onsite wastewater system permit data on paper that has never been digitized.

8.1.2 Sources of Existing Data

Permit data can contain a wealth of information about each wastewater treatment system. Permits are found at the local board of health, or whatever jurisdiction regulates the wastewater treatment system. The data contained on permits vary from jurisdiction to jurisdiction. In addition, permit forms are changed from time to time, so any jurisdiction with much history in its permit files usually has two or more types of permit forms on record, each containing somewhat different data. With those caveats, the following types of data are often found on permits:

- System type
- Design flow
- Size and location of soil absorption system
- Size and location of septic tank
- Owner's name and address
- Parcel number
- Identity of the designer and installer
- Soil profile and/or results of percolation test
- As-built drawings
- Year of construction and/or repair

In some, but not all, jurisdictions, information on inspections and repairs or upgrades is found in the permit file.

The permit data offer a wealth of information for establishing cohorts used in actuarial studies and for using GIS tools. One of the first things to do in studying the reliability of decentralized systems in an area is to compile the permit data into an electronic database, if they only exist in paper files, so they can be integrated with GIS and/or easily be used for actuarial studies.

The quality of permit data depends both on how well they were originally collected and how well they are digitized. For example, soil/site assessments require humans to interpret many factors and fit them into a code on a permit form. Soil scientist Michael Hoover has conducted a number of studies of failure rates in onsite systems (Hoover and Amoozegar 1989; Hoover 1979; Hoover *et al.* 1993; King *et al.* 2002) and found only one (King *et al.* 2002) where the soil scientists on the study team consistently agreed with the soil/site assessments on the permits.[22] Transferring data from permits to an electronic database is also an interpretive exercise. Permits are often written by hand and in a style unique to a jurisdiction or a permitting authority, so some interpretation by people trained in understanding decentralized wastewater treatment systems is important. More than one consulting company has attempted to digitize permit data more cost effectively by hiring interns to do the work and then found it necessary to re-do much or all of the work using more experienced employees.

Test centers like NSF International and the Massachusetts Alternative Septic System Test Center (MASSTC) provide testing of wastewater treatment systems. Their testing is short term, generally covering a period of months or a couple years. Some universities also research performance of decentralized wastewater treatment systems. As a general rule, test centers tend to study performance of proprietary technologies, while universities study performance of both proprietary technologies and generic technologies, for example, mound systems. The US EPA also has published relevant literature.

[22] Intriguingly, he also found some of the lowest failure rates where the permit soils/site data agreed with his field assessments.

For performance of individual pieces of equipment, especially electrical equipment, manufacturers may have performance data (Stonebridge 2004).

8.1.3 Collecting New Data

Contact Information for Data on Decentralized Systems

Research from the University of Wisconsin—Madison is found through their Small-Scale Waste Management Project office. A publication list and electronic versions of some publications are available at the project's web site.

E. Jerry Tyler, Coordinator
1525 Observatory Drive
Madison, WI 53706
Phone: (608) 265-6595
FAX: (608) 265-2595
http://www.wisc.edu/sswmp/

The US EPA has published studies on decentralized wastewater treatment systems for decades. The National Service Center for Environmental Publications has a catalog of the US EPA publications; 88 can be found by searching for "wastewater" at http://yosemite.epa.gov/ncepihom/nsCatalog.nsf/SearchPubs?OpenForm&CartID=9657-113711

The same page can be accessed by going to http://www.epa.gov/ncepihom/ and following the "Search the Catalog" link.

The US EPA's National Risk Management Research Laboratory also has lists of publications on decentralized wastewater, at their site: http://www.epa.gov/ORD/NRMRL/pubs/index.html

Finally, US EPA's Office of Wastewater Management has a list of publications related to decentralized wastewater at: http://cfpub.epa.gov/owm/septic/publications.cfm?view=all

North Carolina State University has both performed research and hosted twenty conferences on decentralized wastewater treatment systems. Links to some of their publications are found at http://www.ces.ncsu.edu/plymouth/septic/pub.html

The University of Minnesota's Onsite Sewage Treatment Program has published on wastewater treatment system performance, particularly in cold climates. The information is accessible through the homepage: http://septic.coafes.umn.edu/

The National Small Flows Clearinghouse offers many in-house publications and copies of publications produced elsewhere on decentralized wastewater. A catalog, as well as downloadable versions of many of the publications, is at http://www.nsfc.wvu.edu/nsfc/nsfc_index.htm

NSF International administers Standard 40 for pretreatment units and Standard 41 for composting toilets. A list of units that meet their specifications for these standards is at http://www.nsf.org

Massachusetts Alternative Septic System Test Center (MASSTC) tests pretreatment systems for approval in the state of Massachusetts. Information on systems tested there can be found at their web site: http://www.buzzardsbay.org/etimain.htm

An asset management program and its reliability component relies heavily on location-specific data. If adequate information does not exist in the existing local records, a systematic condition assessment of decentralized systems may be called for. There are many ways to organize this: inspections at the time of property transfer, inspections in connection with septic tank pumpout, intensive inspections of systems in a specific neighborhood or watershed, and other ways. The inspections may be voluntary, perhaps with a monetary incentive for the system owner (such as, a rebate on the municipal water bill or a subsidized pumpout). Alternatively, the inspections may be mandatory. The decision of what trigger for inspection to use and whether to make the inspection voluntary or mandatory depends on what decisions the information will inform and the local political acceptance of mandatory measures relating to onsite systems.

Section 5.3.4 gives a model for determining whether more data are needed for determining failure curves.

8.1.4 Potential Future Data Sources

A national effort to develop a model performance code for onsite wastewater treatment systems may yield organized data on wastewater system and component performance. The National Onsite Wastewater Recycling Association (NOWRA) is developing a “Model Onsite Performance Code” for states and communities to adopt (Caudill 2003; NOWRA 2004). Since the code will be based on the performance of onsite systems, performance data are at its heart. A database called “Model Code Classification Matrices” has been proposed to collect data on both the level and reliability of performance. The database is intended to accommodate data from existing and developing technology evaluation protocols, and to consider data from the field and from test centers.

The proposed database will classify technologies using a method similar to that described as the “process reliability” tool in this document (Section 5.6). Table 8-2 shows what the Classification Matrix might look like for a hypothetical technology for nitrogen removal. The database users specify which types of data they are willing to consider, so that, for example, only field data collected by third-party institutions are considered in the Classification Matrix.

Table 8-2
Example of a Classification Matrix for a Nitrogen-Removing Technology

Performance Level (mg/L NO_3-N)	Performance Reliability as Percentage of Operating Time				
	50%	75%	90%	95%	99%
< 10	X				
< 15	X	X			
< 20	X	X	X		
< 25	X	X	X	X	
< 30	X	X	X	X	

Another potential future source of collected data is through standardized operation and maintenance and/or inspection routines. The Consortium of Institutes for Decentralized

Wastewater Treatment has drafted recommended operation and maintenance (O&M) routines, complete with detailed checklists for each visit (Consortium of Institutes for Decentralized Wastewater Treatment 2004). They also developed a Residential Evaluation Survey, to gather information on residents' knowledge of their onsite system and what their habits are with respect to water use, use of septic system additives, and other practices. The National Association of Waste Transporters (NAWT) has also developed a rudimentary homeowner survey to use in conjunction with inspections of onsite systems (Anderson and Gustafson 2004).

These checklists and the survey are designed to assist service providers in their daily work. If the forms are widely adopted, however, it becomes easier to gather consistently collected O&M data on similar systems from all over the country. By linking the O&M data to information on the Residential Evaluation Survey, it could become possible to factor in usage patterns when evaluating O&M history. A large project like such a national database would be more cost effective if it were integrated into another project, such as the database proposed as part of NOWRA's model code.

Yet another potential source of future data on reliability is through telemetry, the connection of automatic monitoring instruments to modem-based data collection. Telemetry makes possible real-time monitoring of decentralized systems, where no operator is present. Costs for telemetry systems are rapidly falling, so the use of telemetry has the potential to expand considerably. Where telemetry is used, one consequence is that the reliability tools described in this handbook become less important in managing the decentralized systems. O&M schedules might still be set based on historical studies of similar systems, but real-time detection of declining performance makes it easier to service systems before they stop meeting performance standards.

8.1.5 New Types of Data Collection Tools Developed or More Widely Used

Ultimately, for the decentralized industry to acquire more and better data, decisions relating to what data to collect and what systems to use to collect and download the data easily are vital. As a jurisdiction chooses the tools it will focus on, the matter of what data to collect will become fairly easy. The data needed to drive the tools, the information the jurisdiction is required to report for regulatory purposes, and other information requested by peers in the industry will be identified.

The methods to collect the information will represent more of a challenge. The simplest method, paper and pencil systems, can be used. Much of the data available today is still in this form. While the most comfortable for most to use, it usually results in little data being generally available for decision-making. The data usually sits in file cabinets, never to be seen again. Technology, while potentially daunting to some, offers the promise of better decision-making and (after some learning curve) greater efficiency of time.

Many methods are available today to input data into systems. Among these are retyping paper records into spreadsheets or data bases, telemetry or dial-up systems that record information and directly dump the information into computer systems, handheld computers that the person in the field enters information into, and wireless applications where the person in the field inputs data that inputs directly into a centralized repository.

Each of these options has been used as a means of gaining better information for the decentralized industry. Just as surely, the world of technology will expand, providing new options. Of critical importance, is to choose the system that provides the data needed in the most cost-efficient and simple-to-use form possible. Cost efficiency should include the value of staff time in addition to the cost of technology and subscription services to give the decision maker the best information with which to gauge their choices. An example is the question of whether to enter the data into a spreadsheet or a relational database, which is slightly more involved to set up but easier to use in processing large amounts of information.

A relational database (like Microsoft Access) contains multiple tables, each of which stores a particular type of information. The tables are related to each other in a way that makes it straightforward to answer sophisticated questions. For example, a database can easily be used to use Boolean logic to generate a list of all addresses where the onsite system was built before 1980 AND the depth to groundwater is less than three feet OR the soil type has moderate to severe limitations.[23] The same information can be extracted from spreadsheets, but much more laboriously. The ease of extracting such information from a database makes it likely that the curious analyst will try out a larger number of ways to combine information to look for a pattern. Databases can also be dynamically linked to GIS, while some spreadsheets cannot be linked.

Issues such as the criticality of the information must also be considered when considering options. For instance, if a failing pump on a cluster system will result in a discharge to a nearby stream within two hours of occurrence, technology to dial up an alarm to a maintenance worker may be appropriate. However, if the data need is to track the level of sludge in a homeowner's septic tank, a simple means of recording the data so that it may get into a database may be sufficient.

8.2 Data Storage and Retrieval

There are many different choices for storage systems that can handle data useful for reliability and costing analyses. Some analyses can be done in spreadsheets. It is possible to construct one's own storage system using a commonly available database program like Microsoft Access, MySQL, or Postgress. One service provider has done that with data on customers he serves, employing his grandson to construct the database architecture (Stonebridge 2004). Certain municipal management software, like GeoTMS, has permitting functionality that tracks some information useful for reliability assessment.

[23] Such a query might be useful for finding systems to define a cohort (Section 5.3.2) to be investigated for higher-than-average failure rates.

Some software systems have been designed for managing decentralized wastewater. In Massachusetts, SepTrack was developed for local boards of health in the 1990s. Carmody Data Systems and Stone Environmental offer customizable, web-based databases that have been used from the municipal to the state level, and Ayres Associates is just completing development and release of a similar product.

Wastewater-specific databases are marketed primarily as management tools, but they have been used in conjunction with reliability studies. One such program was used in a project for the City of Malibu, California, where data on decentralized systems was connected to a MODFLOW model of the hydrology of the part of the city nearest Malibu Creek, Malibu Lagoon, and Surfrider Beach. The project modeled the potential for bacteria and nitrogen from decentralized wastewater treatment systems to travel to the surface water. Areas with greatest potential for contributing bacteria and nitrogen were identified, and time of travel for nitrogen and bacteria was found to range from six months to 50 years.

A wastewater-specific database has also been used for numerous needs assessments, like that in Holliston, Massachusetts described in Chapter 5. In these cases, data on the types and management history of wastewater treatment systems have been used to assess the management implications of hypotheses about reliability, for example, "older systems near water need to be managed closely or upgraded in order to meet treatment performance standards." Hypotheses about reliability have also been tested by assessing the frequency of repair permits issued to certain types of systems.

Design of databases for decentralized wastewater has focused primarily on managing systems, not on assessing reliability. The wealth of data that can be stored in these databases, especially when it is coupled with GIS, could make them powerful tools for reliability assessments.

There is a tension between centralization and decentralization of databases for onsite systems. Large, centralized databases can collect information on many types of different systems; the abundance of data makes it possible to define very specialized cohorts and still have enough data to draw statistically significant conclusions. On the other hand, some local authorities are reluctant to share disaggregated data with state regulators. Attempts to create databases spanning state boundaries also face the conundrum of lumping or splitting systems according to differing terminologies. For example, a "mound system" in one state may be much different than a mound system in another state, because of the type of sand used.

During the two workshops held in conjunction with this project, some participants expressed an interest in reliability databases being in the public domain. If the database program is in the public domain, it is free for anyone to use— "freeware." The Massachusetts Department of Environmental Protection's Septic System Tracking Program is one such program.[24] It is not clear whether the program runs on newer versions of Windows or whether there is any user support for it. The private sector programs, while carrying a price tag, come with user support.

The data can be in the public domain in the sense that they are freely available to anyone who wants them. In some states, records like wastewater treatment system permit files are public

[24] Available for download at http://www.buzzardsbay.org/download/dep-t5track.exe

records and thereby freely available. The way the database is set up can, nonetheless, greatly influence who has access. The data in a program that runs on a single computer or a local server in the health department office cannot easily be accessed by those outside the health department, whereas the same data in a web-based program can be accessed from anywhere in the world.[25]

Any permutation of public/private database program and data is possible; a private program can make data publicly available, and a freeware program can be used with privately held data.

Issues to be considered when deciding on a database program and whether the data are to be publicly available include privacy and security. For privacy, do system owners want all their permit data, including their names, addresses, assessor's numbers, and other data, to be freely available to anyone in the world? Are there ways to selectively make information available, so that some users can see everything but other users cannot see personal information? Security is tied to the integrity of the data—are there multiple backups, at least one off site? How easy is it for an unauthorized person to gain access to the data and change them?

Municipalities, other jurisdictions, and RMEs have a range of options available to them for database programs. Service providers are left to construct their own, at this point, or to try to make use of the programs targeted at local wastewater authorities. Whatever form the database takes, having permit, cost, and maintenance records in electronic format makes it easier to transfer to a different database in the future. The jump from paper records to electronic records is generally bigger than the jump from one database to another, both in terms of cost and of analytical power.

8.3 Storage, Care, and Manipulation of Data

For the decentralized wastewater industry to grow, improve decision-making, and improve its cost effectiveness, some level of baseline information will be required. At a national and state level, basic information such as the number of systems, how many systems fail each year (including trend analysis), the impacts on public health and environmental consequences and the cost effectiveness of the industry are important to setting policy, permitting, and implementation strategies. States will require more detailed information, for instance desiring further breakdown of the numbers of systems and failures by type or perhaps within soil groups. A state may also be interested in information relating to who installs, designs, and/or maintains systems as a tracking and evaluative tools. Some states may want reliability data as a means of determining what systems to authorize for use in their jurisdiction.

Regionally and locally, additional information needs will largely be driven by the management goals of the jurisdiction. If the jurisdiction is interested only in how many systems they have, there will be no additional data needs. If they implement a framework system and tools such as those described in this handbook, then the additional data needs will be driven by their choices of goals and tools.

[25] South Carolina is an example of database architecture restricting data access. County health departments use the same program for managing their onsite systems, but each one ties into a local database. They are not designed to access other counties' databases or for anyone at the state level to get access to the local databases, individually or aggregated.

In each case, as much information as possible should be available on a centralized database or spreadsheet. At the local level, this database would hold all information relating to the systems and maintenance of the systems within its jurisdiction. Information from this database could then be easily imported to any analysis or reporting tools used by the jurisdiction, providing maximum efficiency within the system. While at first challenging to accept, efficiency and improved performance of decentralized infrastructure can only occur with some level of centralized information and management.

State and national data systems should feed primarily off of these local systems, but with only those pieces of information necessary for setting state and national policy and implementation rising to their databases. At each level, issues of trust will arise. Historically, data sharing from the local level to the state level, and from the state to national level has been highly charged, not only in the decentralized wastewater industry, but also generally. In all cases, the culprit is lack of trust in how the information may be used in negative ways. It is for these historic reasons that only that information that is truly necessary should be transferred up the ladder. This reporting can be easily accomplished with virtually no keystrokes, saving reporting dollars and increasing efficiency as a result.

Other types of data, such as implementation costing, operation and maintenance costing and activities, and reliability data should also have a national repository; however, for the reasons noted above these would be most effectively implemented by a third party (perhaps a non-profit organization). This database would provide information to all involved in the industry; however, it could be aggregated in ways to protect jurisdictions from the trust-based issues that might otherwise hinder information sharing. This effort would greatly enhance new jurisdictions in making initial estimates of costs and reliability and thus, would allow them to leap forward on their continuous improvement path. In short, the industry would move forward as one in terms of its knowledge base.

As databases are developed, existing systems such as the Environmental Information Data Exchange Network should be used as the means of sharing information. Tremendous investment into these systems has already been made and there is no reason for the decentralized wastewater industry to duplicate these costs.

8.4 Statistical Significance

In Chapter 5, *Reliability Assessment Tools*, a way to test for statistical significance of differences in failure rates was presented. Statistical significance is easier to achieve with larger amounts of data, though it also is important how the samples are distributed.[26] Applications where statistical significance is important will benefit, then, from access to larger databases.

[26] For example, for a sampling protocol using a fixed number of grab samples (such as, 50, 100, or 150), a more accurate measurement of the mean for an effluent parameter (for example, nitrate nitrogen) can be obtained by increasing the number of similar systems sampled rather than increasing the samples taken per system. Four samples per site and twelve to forty sites give a reasonable degree of confidence (Groves 2004; Converse and Nordheim 2004).

However, useful insight into reliability can be achieved without statistical significance. The manager of decentralized systems generally does not try to prove a case beyond a reasonable doubt, but rather, just to understand what actions are likely to lead to better performance. Indeed, the GIS tools described in the chapter on Reliability Tools have often been applied to assess the implications of reasonable but untested hypotheses about which systems are most likely to contribute to resource vulnerability.

Even false hypotheses can lead to better management. For example, the service provider described in Section 8.1.1 learned from the pump manufacturer that the contactors were burning out much faster than they were expected to, and thereby was led to discover that he would be installing the wrong floats. Even if he had not had access to the “true” failure curve information, and had believed that the contacts did not last long in service, he could have improved performance by more frequent replacement of the contactors. This hypothetical approach would probably be more expensive than understanding the problem with the floats and replacing them, but it could still lead to better performance (less system down time). If a database is structured in a way to make it easy to frame and answer “what if…” questions, then the user can use it as a tool for discovery and thinking, even if the answers are not necessarily statistically significant.

Statistical significance is more important for questions such as whether to permit a proposed treatment technology to be used or to verify a technology as achieving a certain performance standard. Some questions of cost effectiveness, too, are likely to require statistically significant data to answer. Sensitivity analysis can help resolve how many data are needed to resolve a given question. For example, is it cost effective to retrofit septic tank access risers to grade? Say preliminary calculations show it would take 50 septic tank events (pumpouts and/or inspections) for the time saved to offset the cost of installing the access risers. If a pumpout is scheduled every four years and an inspection takes place every seven years, and (improbably) there is never a pumpout at inspection, it would take more than 125 years to pay back the investment. In this case, it is unlikely to matter whether the calculations were off by a factor of two or even four; the payback time is too long for most people to want to make the investment. If the riser retrofit is being considered for an aerobic treatment unit that gets quarterly inspections, then the decision of whether to install the riser would be more likely to be affected by whether the preliminary calculation is off by a factor of two.

8.5 Default Values and Proxy Data

As Seattle Public Utilities has shown (Section 7.5.1) it is possible to improve decision-making and save costs even while using failure curves that are known to be wrong in absolute values (for example, time to 50% failure), as long as they are correct relative to one another (for example, relative life of concrete versus steel pipes). Using the most easily accessible data as *default values*, even if they do not fit the situation at hand exactly, can improve understanding. For example, if detailed field data on soil types are not available for use in Geographic Information Systems (GIS) tools, then the Natural Resources Conservation Service (NRCS) maps can be used exclusively for a first cut. Sensitivity analysis for any calculation can be performed by testing the effect of mapping the entire region as the major soil type that is most- or least-suited for onsite systems. In homogenous areas, like sandy coastal outwash plains, such changes may make little difference in GIS analysis.

The risk-cost approach to mounding analysis described in the Chapter 7, *Costing Tools*, provides a model for assessing how important it is to gather more data. A similar approach could be applied to many other situations. Further insight into how to decide when more detailed data would be useful, and how to make decisions with the data at hand, can be found in the literature on process engineering (for example, Rudd and Watson 1968).

Proxy data (or *surrogates*) are those that are easy to collect and that can replace data that are more expensive to collect. For example, biological oxygen demand (BOD) and nitrate tests take days to process and are costly compared to many tests that can be taken in the field. As part of the process of verifying that a technology achieves a performance standard that requires a lab test (such as, BOD_5), it might be useful to check how field tests correlate with the lab test results. Field tests to consider including in the verification protocol are settleable solids, turbidity, dissolved oxygen, and pH. One participant in a workshop conducted as part of this project suggested emphasizing tests that could be done in 30 minutes and for less than $30.

9 SUMMARY AND CONCLUSIONS

The wastewater challenges facing communities today are more daunting than ever. Funding for new centralized systems is strained, development pressures are high in many regions of the country, and interest in the pattern in which development occurs is at an all time high. At the same time, technology choices for decentralized wastewater systems are increasing, there is a dawning recognition that decentralized systems are not a temporary solution to wastewater challenges, and recent research efforts are identifying new challenges for and impacts from septic systems. The decentralized wastewater industry is at a critical transition point.

For decentralized wastewater systems to fully be accepted as a viable long-term solution, critical changes must occur within the industry. Some of the more critical items include:

- Improved alternatives analysis
- Enhanced maintenance procedures
- Adoption of performance standards
- Enhanced management programs that ensure compliance with performance standards
- Enhanced development of technology
- Public education and involvement

Each of the issues noted above is highlighted in the fictional case study, *Jerry's Awakening*, presented in this handbook. While fictional in nature, this case study is derived from real issues from around the country, put together to highlight the potential power of the tools presented in the handbook. Most readers of this document will easily recognize situations they are familiar with that match up with parts of the case study.

It is this matching of experiences that begins to provide solutions to the challenges noted above. If the experiences match, then the tools provided here become means to solve real problems while increasing the industry professionalism, decentralized system acceptance, and the use of new technologies.

The framework provides a method for thinking through each community's or jurisdiction's unique challenges, although few will face the breadth that Jerry faced in the case study. At its essence, the framework is a standard planning cycle, modified for use in this industry. The process is to:

- Identify the problem
- Identify outside influencers

- Develop goals
- Consider a range of alternatives
- Make a decision
- Act
- Monitor
- Evaluate
- Start again as needed

Three issues differentiate the framework from the standard planning model. The outside influencers are many, and they wield great authority and power over the planning process. Improved decision-making in the decentralized industry must be supported by a strong information system. Finally, good information must be available at every step of the process. As a result, this framework places stakeholder involvement and an information system at its core.

Use of the framework will assist communities, management entities, and regulators to address many of the critical issues central to the growth of decentralized infrastructure. The process ensures that the widest range of alternatives that might solve current issues and achieve community goals are evaluated. These goals can include regulatory compliance and broader environmental, human health, growth, economic, or community goals.

For a regulator, the framework provides assurance that resources are directed to technology and systems that are truly necessary, while providing greater assurance that performance standards are appropriately identified and ultimately met.

Implementing this framework will provide one other critical benefit: public education relating to water-based infrastructure. Use of the framework requires public involvement, potentially bringing these basic infrastructure issues into the community debate. As a result, decentralized systems will become better accepted and, when they are selected as the preferred alternative, an informed electorate will be much more likely to approve the implementation of such projects.

Framework implementation requires methods and tools to more accurately evaluate costs for decentralized wastewater projects. Life-cycle costing provides a useful method for accomplishing this task. Cost considerations may include only the capital costs and maintenance costs of solutions. For communities with other interests, these tools will enable costing of impacts to the environment and human health, as well as societal costs to be considered in comparing alternatives.

Today’s electorate is interested in lowering infrastructure development costs. Capital costs are expected to be fully developed and considered before a project is approved. Consideration of capital costs alone, however, can result in the approval of projects that cost much more than other alternatives. Understanding maintenance costs up front would likely change the outcome of a bond or approval vote. Similar analysis can be performed for other environmental and societal costs, though they require more public dialogue since who pays for those costs less clear. Such methods may challenge the public, since the costs of illness, for example, are borne by individuals, the health care industry, and insurance companies. This level of detail will not be necessary in every case, but is possible if the user has the interest.

Activity-based costing focuses on understanding the true cost of specific actions, and is useful for optimizing operation and maintenance costs and actions. This information can be used to influence future decisions by incorporating solid estimates for operation and maintenance activities into project development using the framework and the life-cycle costing tool.

Operators and jurisdictions generally keep track of costs using traditional bookkeeping methods. Capital expenditure, labor, and materials are typical listings. Activity-based costing suggests another way—accounting for costs based on activities. Operators can then understand what drives the costs of operating and maintaining systems. The result of such analysis may be changing a process, knowing which parts to stock and have on the truck, or even understanding when action is not required or cost effective.

By using activity-based costing, jurisdictions can enhance the value of alternatives analysis and lower their operation and maintenance costs over time. Regulators can use this tool for better financial planning, enhanced maintenance, and thus better adherence to permit requirements and better evaluation of new technologies.

For new technologies to gain wide acceptance and for decentralized systems to provide assurance that permit conditions can be met and water quality and human health protected, the reliability of these systems must be enhanced. Many tools exist to assist the industry in meeting these challenges.

Failure curves are a simple actuarial tool that plots the frequency of failure of systems or components over time. For typical pumps, septic tanks, technologies, filters, or entire systems, industry-wide data regarding failure over time can be plotted. This tool enables the operator to understand when certain elements are likely to fail and to plan accordingly. Using this tool would result in lower overall costs, fewer system failures, and enhanced environmental and human health conditions.

Process reliability is a simple graphical tool that plots various types of data on a log scale to ensure that a predetermined level of performance can be achieved. Data from the treatment system of interest are plotted on a log-scale graph, and a best-fit line through the data is calculated. By drawing a line parallel to the best fit line that will run though the mandated standard or performance goal, one can determine the level of treatment necessary to meet the goal. This tool can enable understanding of the impacts of mandated standards and the implications of performance standards.

Failure modes and effects analysis is a reliability tool that combines the best of simple process with the best of intuition and ease of use. It may be performed simply or in a very detailed test environment. It is useful in enhancing maintenance procedures and in assisting operators to meet performance and regulatory goals.

In its simplest form, the process is as follows:

- Understand the function of interest
- Determine the failure mode occurring
- Consider the possible causes of the failure
- Understand the effect of the failure

This tool can be used in either a prospective risk assessment process to determine how to apply preventive maintenance techniques, or to troubleshoot existing problems.

To conduct a risk assessment using failure modes and effects analysis, one considers all the functions of a wastewater system, from fixtures in the house, through tanks, filters, pumps, and dispersal. At each step, the ways each element could fail are listed along with the specific causes. Finally, the impacts of each element's failure are considered. This enables understanding of those elements that might impact human health, the environment, property, or societal values.

Geographic information systems provide the ability to minimize risk, site decentralized systems, provide the public with clear information about system placement and choices, and to depict other information such as environmental impacts and potential zones of higher threat to human health. This tool can influence decision-making in the framework process, costing decisions in life-cycle costing, and the reliability and maintenance requirements of systems. For example, by plotting areas of high water tables, poor soils, and shallow bedrock depths, areas of a community that are not suitable for onsite systems will emerge. When protection zones around wells and other issues of local concern are added, the tool can show where systems at risk of failure may be located and where additional precautions may be warranted. The tool could also incorporate impaired waters and, if available, health data, enabling understanding of the possible connection of failed systems with real impacts.

The risk-cost model can combine the matters of cost and reliability. This method allows the allocation of funds based on the risks and costs of failure. By plotting the cost of any particular failure against the probability of that failure, the decision maker gains valuable insight into how best to invest resources.

The methods and tools introduced in this handbook represent proven techniques that exist and can be implemented today. Many additional tools exist that users may investigate. Tools to move the barriers in the decentralized wastewater industry exist and simply require dedication to use and a commitment to data collection.

Surprising volumes of data were uncovered during the development of this handbook (see Chapter 8). However, these data are often hard to find, of uncertain quality, and not established in a central repository. This challenge should not impede the user from implementing the framework or tools. Rather, the industry must act on the need for solid information on costing, reliability, risk, and system information. Until this happens, many of the tools may use surrogate or estimated data as a way to start if actual data are missing. Experience in costing, the use of

Weibull curves for reliability, and other techniques enable the user to find a place to start and then to revisit initial assumptions as implementation occurs.

The use and implementation of the tools found in this handbook do not represent an end to the data, tools, or methods necessary to meet the challenges that the decentralized wastewater industry faces today. These tools represent the basics of asset management approaches, and provide a place to begin and a way to reach the goal of providing infrastructure that is cost-effective, reliable, and designed to meet the goals and standards of importance to the homeowner, community, state, and country.

Jerry left Valerie's office with approval for a slightly more elaborate testing scheme than he had hoped for, but less complicated than the one suggested by the Strategy Level table they had looked at. Both agreed to think through whether and how the approach could be adopted in the state, but to keep to existing guidelines for now.

Jerry headed for the Ancient Mariner bar, where he was meeting Tom, the spokesperson for SBEA. They were going to discuss the inspections of the 110 systems the GIS analysis had identified. Inspections were about to begin in a week, the beginning of the wettest time of the spring. He reflected on the meeting with Tom and other SBEA members after he and Ray had decided on the 110 systems to inspect, with the help of Barb's analysis. Jerry had started out on the wrong foot when he explained the decision had already been made, and Tom had countered that he wanted all 603 systems inspected the first year. But when Jerry backed off and said that he was just presenting their preliminary thoughts for comment, they had reasoned together through the logic of starting with 110. Jerry thought proudly of how he had offered to do the 197 inspections of systems to houses within 40 feet of water, if SBEA would help them talk to the homeowners. Tom considered the suggestion, but ended up accepting the 110 systems and offering to write a letter endorsing the inspections for Jerry to send out to the homeowners. After that, Tom and Jerry had been meeting almost monthly to discuss one water quality issue or another.

Jerry's head spun sometimes when he thought about all the new ways of thinking about wastewater reliability and costing he had dabbled in over the past six months. He had submitted plans, costs, and a rate structure for the new subdivision, and was well on his way to spinning off a PUC-regulated utility. Activity-based costing was revealing all sorts of ways to save money, or at least pass on costs, in his business. The digitized information and GIS tools were enabling him to ask all sorts of questions about The Zone's systems that he had never thought of before. And they were about to launch an inspection effort that would start settling the question of how much onsite systems were contributing to the water quality issues of Sandy Bay. Jerry walked into the Ancient Mariner a little early and ordered a beer, drinking a silent toast to the accomplishments of the last half year. A few minutes later, Tom showed up, and together they toasted the success of the inspections. Jerry was a little suspicious that he and Tom meant different things by "success," but he did not press the point.

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11 ACRONYMS AND ABBREVIATIONS

3D	Three-dimensional
ABC	Activity-Based Costing
AMSA	Association of Metropolitan Sewerage Agencies
AWWA	American Water Works Association
BOD_5	5-Day Biological Oxygen Demand
CBA	Cost Benefit Analysis
$CBOD_5$	Carbonaceous 5-day Biological Oxygen Demand
CBS	Cost Breakdown Structure
CEA	Cost Effectiveness Analysis
CFU/100 mL	Colony Forming Units per 100 Milliliters
CSIRO	Commonwealth Scientific and Industrial Research Organization
ESRI	Environmental Systems Research Institute
FAME	Failure Modes and Effects Analysis
FOG	Fats, Oils, and Grease
GIS	Geographic Information System
Gpd	Gallons per day
IRP	Integrated Resource Planning
L	Liter
LCC	Life-Cycle Costing
MANAGE	Method for Assessment, Nutrient-loading, And Geographic Evaluation of watersheds
mg/L	Milligrams per liter
MTBF	Mean Time Before Failure
N	Nitrogen
NOWRA	National Onsite Wastewater Recycling Association

NPV	Net Present Value
NRCS	Natural Resources Conservation Service
O&M	Operation and Maintenance
PV	Present Value
RME	Responsible Management Entity
ROW	Right Of Way
SAS	Soil Absorption System
SBEA	Sandy Bay Environmental Alliance
SPU	Seattle Public Utilities
SSURGO	Soil Survey Geographic data
STEP	Septic Tank Effluent Pump
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
US EPA	United States Environmental Protection Agency
UV	Ultraviolet
WERF	Water Environment Research Foundation

A ADDITIONAL RELIABILITY AND COSTING TOOLS

Reliability Tools

Engineering/technical reliability tools are used for determining or predicting the probability, mode, and location of asset failure. Mechanical, structural, and system reliability tools feature in this group, as failure may occur due to breakage or dysfunction of components or may be related to the treatment process itself. Examples include:

- **Probability assessments**, such as mean time to repair and operating availability.
- **Critical component analysis**, where probability assessment is concentrated on the components identified as being most critical to system performance. The majority of maintenance for a piece of equipment is often caused by a relatively few critical components. If these critical components are identified and their performance studied in more detail, it is possible to discover how relatively small inputs of maintenance attention can give large results in terms of improved performance. Management of decentralized wastewater systems with a higher number of components, like pumps and blowers and control panels, may find more use for critical component analysis than management of conventional gravity systems.
- **Statistical field sampling** of a subset of wastewater treatment systems can provide data on what factors correlate with poor performance. In order to provide statistically valid results, Hoover (2002) has devised a step-by-step procedure distilled from experiences in a number of studies (Hoover 1979; Hoover *et al.* 1993; King *et al.* 2002; Lindbo *et al.* 1998). Statistical field sampling is an ambitious exercise, involving a team of a half dozen or so people representing expertise in soil science, onsite systems, and statistics, plus local authorities. Designing the study can take half a year or more by itself, and then the data are collected intensively over a few days by a number of teams working in parallel. Detailed statistical analysis and peer review is part of both the study design and producing the final report.
- **Systematic troubleshooting methods** to evaluate the causes of failure are important to help achieve uniformity in reporting. Some examples include *FACTSS* (Failure Analysis Chart for Troubleshooting Septic Systems (Adams *et al.* 1998), the *Inspection Manual for Onsite Systems of the National Association of Wastewater Transporters* (NAWT) (unpublished), *Septic System Check-Up: The Rhode Island Handbook for Inspection* (Rhode Island Department of Environmental Management 1997), and a current project of the Consortium of Institutes for Decentralized Wastewater Treatment.

Costing Tools

Analysis of Asset Cost Inventory

To make good use of an asset information system, its contents may be analyzed to look for trends so that individuals or organizations can be proactive about maintenance and make informed decisions. One of the WERF asset management tools specifically mentioned was tracking O&M costs by asset in the area of maintenance management, and this is one example of how the cost inventory may be analyzed.

An asset cost database can be analyzed to:

1. Track actual maintenance costs according to various factors, such as pipe material, location, and technology type

2. Track costs to respond to failed systems

Economic Life Replacement Analysis

"Economic life" of a component can be defined as having been reached when the cost of replacement is less than the cost of continuing to repair it, when all costs are included (Young and Belz 2003). This tool has been employed in the centralized wastewater sector. It involves creating a model to determine the point at which it costs less to replace the pipe rather than leave or repair the pipe. This model is based on factors such as:

- Repair costs
- Historical frequency of breaks
- Commercial loss of water
- Replacement cost
- Discount rate
- Residual value of the replacement component in 20 years (end of Net Present Value period)
- Likely increase in breaks in the future (Saunders *et al.* 1998 as cited by Young and Belz 2003)
- Social cost to the community (for example, discontinuity of service)

Some people have pointed out limitations to models of economic life of a pipe. A common problem with some such models is the use of a normal distribution to portray failure of a certain type of pipe. However, this assumes that the pipes are all exactly the same and used under the same conditions, which is not the case. Stresses due to soil conditions and use differ from pipe to pipe and therefore using a normal distribution will not give accurate results. In response to this, others (Silinis *et al.* 2003) suggest the use of an "aggressivity index" that accounts for spatial variation (for example, influence of soil type on pipe corrosion) through analysis of records of pipe failures to account for this factor.

Furthermore, useful life as a concept is just being tested now. The current infrastructure is thought to be reaching the end of its predicted "useful life", and yet many cases show examples where that prediction has been significantly outlived. The best response to this conundrum is to keep reasonable local records. Detailed records of failures are needed to provide enough information to make this factor accurate enough to be useful.

The implications for decentralized wastewater are that local context is of paramount importance. For centralized systems, it is only the pipes that are subjected to a wide variety of conditions depending on their location. In the decentralized field, not only the pipe-work, but also all parts of the system are subject to a local set of conditions. Modeling efforts on economic life of components must take into account the local context; otherwise, they are unlikely to yield useful results.

An extension of the economic life replacement analysis is to consider sets of assets concurrently rather than individual assets one by one and generate "Nessie curves" (see the illustration in the text box, Section 3.3.2). This approach involves a long-term view of infrastructure replacement and requires a database with information on asset condition and reliability, plus rate and cost of renewal and replacement. This information enables generation of the "Nessie curves" that show how well the rate of renewal and replacement of the infrastructure matches the anticipated rate of deterioration over many decades to come. The Nessie curve enables one to understand the scope and nature of the future infrastructure or asset cost requirements. This tool relies on a sound knowledge of the economic life of equipment. It is therefore not useful at this point in time in the decentralized industry, but will be useful in the future when greater understanding is reached through appropriate data collection and analysis.

Cost-Benefit Analysis (CBA)[27]

Cost-benefit analysis helps one evaluate the favorable effects of an action and the associated costs of that action. The favorable effects are called benefits and the economic costs are deemed opportunities foregone. The main objective of CBA is to compare social costs and benefits. Various economic methodologies estimate the value of anticipated benefits and costs.

This analysis always includes comparisons of costs and benefits to the whole of society. "Whole of society" implies all stakeholders, including the public or community that can be potentially affected by the decision. In a CBA analysis the costs and benefits are estimated over time with projections made into the future. These streams of monetary values are then discounted back to a present value based on a predetermined discount rate (as shown in "the time value of money" and in the life-cycle costing tool).

[27] Further detail on cost-benefit analysis and cost-effectiveness analysis is available in US EPA (2000a).

When deciding which benefits should be included in an analysis, one needs to consider "avoided costs." "Avoided costs," or perhaps more easily understood as "avoidable costs," are costs that, relative to a base case or business-as-usual course of action, are avoided by certain choices about how things are done in the future. Resources are available to aid this process (Feldman *et al.* 2003).

For options that improve reliability of decentralized systems, avoided costs that could be included are:

- Avoided environmental damage
- Avoided costs of other damage or risk posed by failure
- Saved water or saved energy (both operating costs and avoided or delayed augmentation or capital costs)
- Avoided maintenance costs (for example, if the option includes water efficiency measures that reduce hydraulic load on the system)

Integrated Resources Planning (IRP) Framework

Integrated resource planning (IRP) is an open, participatory, strategic planning process, emphasizing least-cost analysis of options for meeting utility supply service needs.[28] It was developed for the electricity industry in the United States in the 1980s. Its aim was to compare energy demand management programs with increased generation as sources of supply. The basic premise of IRP is that the utility should treat bulk supply and conserved supply as equivalent. Demand side management is central to IRP, with demand management being any program that modifies (decreases) the level and/or timing of demand for water or energy. Demand management programs are designed to promote conservation through either changes in consumer behavior or changes to the stock of water or energy using fixtures, such as showerheads, toilets, or light bulbs.

An understanding of the different cost perspectives of different parties in the decentralized wastewater sector puts the regulator in a good position to develop incentives to promote reliability. For example, one way that incentives may be set up to encourage homeowners to look after their system in a way that will ensure its reliable functioning, is to have them pay for monitoring tests. If after a period it is shown that a household is looking after their system, these customers can then be rewarded by the reduction of monitoring tests from quarterly to annually—giving them a cost saving and therefore a motivation factor.

The concept of local integrated resources planning (LIRP) has recently been developed. It extends the usefulness of IRP. Local integrated resources planning came about as a result of the realization that planning based on system averages obscures particular problems and opportunities. Instead, LIRP uses area-specific and time-specific marginal costs: these costs depend most on distribution and local transmission costs (unlike system-level costs, which depend most on generation and bulk transmission costs). From these analyses, it is possible to

[28] Further information about integrated resource planning is available in Vickers (2001) and Beecher (1995)

create targeted distributed generation or demand-side management investment. Siting of these new strategies is in areas with high avoided costs—in these places distributed generation or targeted demand-side management will be particularly cost-effective.

Some examples of where location and time affect reliability decisions for decentralized wastewater and therefore where LIRP might be applicable are:

1. Design flows are usually based on peak daily use as a safety factor against spikes. An RME found that pumps were burning out very fast, and discovered the families concerned were doing a tremendous amount of laundry on weekends, exceeding the design flows. Some localized remedial action would improve reliability in this instance.

2. The depth of pipes below ground varies in importance depending on whether an area freezes or not. In areas where there is freezing, this is a significant issue, and can cause some regions of the country to bury the pipes at great depths. (Vermont requires a six-foot bury depth on most water/wastewater pipes.) For other parts of the country, this is a non-issue. In fact, pipe quality can be further reduced because of less stringent structural integrity requirements. Again, achieving a required level of reliability at minimum cost relies on understanding the local context and the relevant risks that need to be minimized.

Integrated Resource Planning: Less Water Leads to Less Wastewater

In the Warren demonstration project, the inclusion of water use in the user fees was done to help conserve existing water resources, and to help allow for a small amount of growth using the actual water use going to a system compared to design flows as the basis for permit changes. During the planning process, the Warren wastewater advisory committee wanted to include incentives/ways to encourage conservation of water while taking care of the wastewater problems. They considered adding/upgrading water fixtures, but it was difficult to figure out which houses needed what types of new fixtures. The committee was also concerned about base costs for some fixed income individuals (one to two people/household). They decided to build a water-use calculation into the user fees, so that if water use was less than average, the user would pay less; if more, the user would pay more. (This part of the rate calculation is about 20% of the total). They are installing water meters on individual well lines and will take readings with a sensor “gun.” Since there is no centralized water system, this will not impact anyone's water bill. It is intended to help track the actual flows going into each system and identify peaks where someone may have a plumbing leak, or other problems, and keep the flows well within the design limits, which reduces the probability of failure and associated environmental risks, viewed as important by the Warren community. The largest cluster system at Brooks Field may experience an additional impact. Just like at a wastewater treatment facility where the original flows are based on design flows, once the RME has been tracking the actual flows for a period of time (usually two to three years), the RME can request adding new flows based on the actual capacity of the system, not just the design limits. This will be important for systems that want to build in a certain amount of growth, which will be many of them, particularly since these systems will first be designed to serve existing growth centers in villages.

Cost Perspective Tests

Cost perspective tests are a way of looking specifically at a particular party's cost perspective to determine whether a program (or option/scenario) would be beneficial to them or not. These were initially developed for economic analysis of demand-side programs and projects[29] and include five tests:

- Participant Test
- Ratepayer Impact Measure Test
- Total Resource Cost Test (and variant Total Societal Cost Test)
- Program Administrator Cost Test (utility perspective)

As the names suggest, each test focuses on a particular stakeholder or group of stakeholders. Using these cost tests both individually and together opens up opportunities to negotiate different funding arrangements, sharing the costs across stakeholders to provide societal benefits of improved public health, environmental, and societal risks.

[29] For further detail see *California Standard Practice Manual: Economic Analysis of Demand Side Programs and Projects,* October 2001.

B NEXT STEPS ON THE PATH

The framework, costing tools, and reliability tools described in this handbook provide users with methods and tools to begin integrating better decision-making and reliability into the design, regulation, operation, and maintenance of decentralized wastewater systems in the United States. However, gaps still exist in the current collective knowledge, and additional tools exist or may be developed to assist the industry in taking the reliability of systems to a level beyond what is contained in this handbook.

This appendix contains ideas for future research, project ideas, and industry needs that will help the industry to move forward on the path to reliability. Where multiple versions of projects are offered, they are intended as different ideas that advance a core issue. It may be possible to combine versions into an integrated project, or to consider versions as complimentary phases of a broader project.

First Tier Projects

Project 1—Gather More Input-Output Data on the Different Units That Comprise Onsite Systems

With better data on the variability of performance for system components data, interested parties can use probabilistic models to evaluate onsite systems comprised of a variety of individual components. These models make it easier to accurately compute the design mean to use, which will allow meeting a given effluent quality standard X% (for example, 99%) of the time. This project should encompass both monitoring of treatment system components and evaluation of monitoring systems and sensors, in addition to monitoring treatment unit processes and components. The ability to model these systems enables more effective risk assessments.

Project 2—Identify Barriers to Implementation of Tools and Pilot a Program to Overcome One of Them

Version A: Identify barriers to implementation of the tools described in this handbook. This project will enable a full understanding of barriers to implementation and, more importantly, will identify and evaluate solutions such as policy changes, education, or new business models.

Version B: Dispersed ownership and operational responsibility is a particular barrier to using the tools and framework identified in the handbook. This project would develop a pilot program where the study team works closely with one or a few responsible management entities or jurisdictions to apply reliability and costing tools to decentralized systems.

Project 3—Refine the Asset/Risk Management Framework Through Collaborative Action Research with a Responsible Management Entity, Service Provider, or Jurisdiction

The asset/risk management framework presented in the handbook is well-developed on a conceptual level. To maximize its usefulness to managers of decentralized systems, this project will apply the framework to one or more existing demonstration sites (or other case study sites). Management actions will be conducted on the steps in the framework, and the outcomes of these actions will be monitored for efficiency, efficacy, and effectiveness in achieving desired outcomes.

Version A: This project specifically focuses on setting up an asset management information system and data protocols for both reliability and broader risk analysis at the project site(s).

Version B: This project applies asset management techniques to a case or cases in decentralized wastewater treatment, to

- Assess the condition of decentralized wastewater treatment systems
- Determine the dominant mode(s) of failure
- Find the dominant cause of the failure mode(s)
- Use life-cycle costing to find the least expensive way or ways to address failures
- Demonstrate the use of cohort analysis

Project 4—Gather and Assemble Useful Data for Reliability Analysis in the Industry

Set two to five performance standards and gather performance data for a range of systems over time. Follow 20 to 40 units of each type of system investigated for 10 years or more to obtain a longitudinal set of data. Since government funding for such a duration is unlikely, this project could be developed through a combination of funding organizations including government, responsible management entities, and testing centers or universities.

Subproject: Demonstrate a method for describing the probability of failure over time of soil absorption systems (SAS) in decentralized wastewater treatment using one or more cases.

The method demonstrated for describing the probability of failure over time of SAS will build on previous research, which primarily focused on symptoms of failure (such as surfacing of effluent). This project will also track causes of failure. Surfacing of effluent occurs for a number of very different causes that may have different probability distributions. Addressing different causes separately enables construction of probability distributions that show what type and timing of intervention will most effectively prevent failures.

Project 5—Develop Elements of the Framework That Were Not the Focus of this Project

The proposer develops and applies risk assessment/reliability analysis tools for asset management in the decentralized wastewater field beyond tools for technical risks. This work builds on the work done by Oak Ridge National Laboratory on risk assessment for decentralized wastewater and builds on the current project's tools for asset management. The project includes collecting and collating risk assessment tools for ecological, health, and socio-economic risks. The initial research and tool development would be applied to a selection of demonstration sites.

Project 6—Develop and Ground-Truth a Life-Cycle Costing (LCC) Methodology for Onsite Wastewater Treatment Systems

Version A: Use LCC to optimize management of an existing set of systems. Working with three to five case study locations that contain varying biophysical characteristics and management levels, use activity-based costing to determine the true costs of management and maintenance of each set of systems. From this base, develop a life-cycle costing methodology that predicts the costs of a variety of management scenarios. Analysis of the public acceptability of these costs will be integrated into this project.
Version B: Develop and ground-truth an LCC methodology for new installations. This project will focus on the predictive power of life-cycle costing for different system types. The cost data available will be less precise than for existing systems, and the LCC methodology developed must account for this. This project is a long-term venture, and will likely require a funding scenario similar to that mentioned in Project 4 above. A critical first step for this project is an understanding of how much data, and thus how many years of research, will be required to develop a model with acceptable predictive capability.

Project 7—Use Existing Data for Reliability Analysis

Version A: Demonstrate the use of existing digital data sources on decentralized wastewater treatment systems in reliability studies. Potential data sources include state permits, local permits, and databases set up specifically to facilitate management. Concentrate on data that are already available digitally to avoid the cost of digitizing paper records. Select five to seven cases for detailed analysis. For each data source, demonstrate the ways it could be used to answer questions about reliability, and identify the most important changes needed to significantly improve the data source's usefulness in determining wastewater system reliability.

Version B: Engineering reliability and life-cycle costing require adequate data. Investigate and determine exactly what tools are needed to manage and mine data as it becomes available. One approach is to examine other industries (for example, energy), look at the tools in use, and assess each tool's applicability to decentralized wastewater.

Project 8—Training and Education

New information is provided both in this handbook and through many other sources. A simple "how to do it" process for system managers would assist those managers in implementing these techniques and tools. Regional workshops, webinars, or technical sessions at national conferences are all opportunities to provide such training.

Second Tier Projects

Project 9—Demonstrate the Use of Risk-Cost Analysis in Setting a Community's Priorities for Management of Onsite Wastewater Treatment Systems

In a community with a responsible management entity that wishes to begin managing their existing onsite systems, develop a risk-cost analysis to help determine the type of management for each system and where the management program is to be implemented first. Establish performance standards. Develop a probability estimate of each system not meeting the performance standards, considering factors like system age and depth to groundwater that influence reliability. For the cost estimate, consider the consequences to human health and the environment of the system not meeting the performance standards.

Version A: Use data from a community that has developed a management program using some notion of risk or vulnerability assessment, and recast the data in terms of risk-cost. Describe and evaluate the differences between the original method used and the risk-cost tables.

Version B: Demonstrate use of risk-cost analysis in a community that is developing a management program for the first time, working with the community.

Project 10—Develop Training Modules Around the Tools Identified and Illustrated in the Handbook, and Present the Modules Around the Country in a Series of Two-Day Workshops

The first day is a presentation of the tools and the framework, and on the second day, everyone rolls up their sleeves and figures out how or whether to apply the tools to an individual case or cases brought by the participants.

Project 11—Add / Develop Additional Tools for the Toolbox

This handbook includes many tools, relating to costing and reliability. Those highlighted appeared to the authors as the most advanced and useful for today's managers. Dozens more were evaluated and dismissed for purposes of this handbook. However, many hold promise, once additional data is available or once they are further developed. Monitoring and analyzing the further development of new and existing tools in the decentralized and centralized wastewater sectors should be an ongoing, long-term project. The authors suggest such a review and update of such tools occur approximately every three years.

Project 12—Best Appropriate Practice Model

Developing and publishing a Best Appropriate Practice (BAP) model for each of the key assets that make up decentralized systems would greatly assist operators and managers of responsible management entities as well as individual practitioners. We envision this model considering approximately 40 key system components that make up most systems. This BAP Asset Management model should be developed to enable readers to put components together to suit their situation.

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